Hydro-Electricity for Public Supply in Britain, 1881-1894

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Introduction and general background

The rapid growth of electricity supply in the last two decades of the nineteenth century was largely the result of the invention of the incandescent-filament lamp by Swan in Britain in 1878 and by Edison in the United States in 1879. Up to then, electrical development had been slow. Volta's pile in 1800, Oersted's discovery of the link between electricity and magnetism in 1820, and Faraday's work on electro-magnetism in 1821 and 1831, provided a scientific foundation for the development of electric power. Electrical generators to convert mechanical power into electrical power developed slowly from Pixii's crude machine of 1832 to the reasonably-efficient dynamo of Gramme (1870) and Hefner Alteneck (1873) in response to the needs of science and the early technologies of electro-plating and lighting by means of arc lamps. Arcs were suitable for lighthouse beams and for lighting large spaces, but with a typical 1000 candle-power and the need for regular attention were quite unsuitable for normal indoor and residential-street lighting, and had, therefore, encouraged no large-scale development. So it was natural that the simultaneous availability from about 1881 of efficient generators and conveniently-small incandescent lighting elements should be the turning-point of development, leading to rapid expansion of electric lighting. The use of electric motors followed more slowly.

The majority of the generators were driven by steam engines, but there was throughout the industrial world a well-established tradition of water power, greatly expanded in the nineteenth century through the introduction of the turbine around the middle of the century. So it was again natural that where water power was available it should be applied to electricity generation. Hydro-electricity, as it later became known, was significant from the beginning in many countries, and still is. France, Switzerland, Italy, the United States, all used it greatly, and still do. They have high mountains and long, large rivers. But in Britain we have very little hydro-electric power. Our total potential water power is small relative to that of other countries and relative to our needs. Moreover, in the days before the electricity grid, the hydro-electric potential was all in the wrong places, remote from the towns. Consequently, hydro-electricity has never been really important in Britain. This is, no doubt, why its early history in Britain has been so neglected.

Most books on the history of electricity supply mention the surprising fact that the world's first hydro-electric installation was in England. This was at the private house of Sir William Armstrong, Cragside, near Rothbury in Northumberland, in 1880;[1] it was used for lighting the then-novel incandescent lamps developed locally, in Newcastle-upon-Tyne, by Swan. The books also mention the equally-surprising fact that the world's first hydro-electric station for the public electric lighting of a town in September 1881 not only preceded the world's first steam station for that purpose, but was in England, at Godalming in Surrey. Apart from this, little is said about hydro-electricity in Britain before the big developments of the 1930s—but its story is really very interesting.

After the beginning in 1880-1, hydro-electricity was adopted in numerous cases in Britain for the lighting of private mansions and industrial and commercial premises. For the years 1880-94 I have found reports or records of at least fifty such installations. There must have been many others. For public lighting and consumer-distribution in towns, however, the number of hydro-electric installations in Britain was small. For those same years I have found only eight such stations, and of these, only five really gave a public supply in the normal sense. In contrast, by 1894 there were in Britain at least ninety-one public-supply or 'central' stations driven by steam or gas engines, and on average they were larger. The hydro-electric stations, however, show more novelty and individuality.

I should explain that these numbers are small compared with those applying to France, for example, or the United States. Other countries did not have the development of public electricity supply hampered by unwise legislation as we did between the Electricity Acts of 1882 and 1888. It was thus only after 1888 that electricity supply really began to expand in Britain. It was not until about 1897 that Britain reached the installed capacity that the USA had reached in 1887. In 1894 France had two-and-a-half times the number of central stations that Britain had—and about half of them were hydro-electric.

The first eight[1a] hydro-electric installations for public supply in Britain were, as far as I can ascertain, as follows:

Godalming, Surrey, September 1881
Greenock, Renfrewshire, March 1885
Wickwar, Gloucestershire, October 1888
Okehampton, Devon, about January 1889
Keswick, Cumberland, January 1890
Lynmouth, Devon, March 1890
Chagford, Devon, September 1891
Worcester, October 1894

These are the installations whose history and archaeology are traced in this article. The first two were essentially experimental and did not last long—a few years at most. While public supply was provided in the sense of street lighting and the lighting of private premises, the supply was not offered publicly to ordinary consumers. Wickwar was not experimental and the public lighting lasted many years, but again the supply was not available to ordinary consumers. Thus the first three in the list were not public supplies in the modern sense; the remaining five were, and they were all reasonably long-lasting. Of those in the list, the Worcester installation was by a big margin the largest, having a water-generated capacity of nearly 400 kW. It was well above the average size of British provincial steam-powered stations, which was in 1894 only 350 kW. Moreover, although I know of six hydro-electric public-supply stations opened subsequently during the remainder of the century, none was anywhere near the size of the Worcester station. (They were Milngavie, November 1894; Fort William, August 1896; Salisbury, December 1898, Monmouth, June 1899; Fladbury in Worcestershire, and Ingleton, February 1900.) Thus it seems sensible to regard Worcester as the climax of nineteenth-century hydro-electricity for public supply, and this explains and justifies my choice of the period 1881-1894 for this article, and also the large proportion of the article devoted to Worcester.

Lest it be thought that Worcester was in any sense a climax also of hydro-electric engineering, I must point out that far larger plants were already in operation on the Continent of Europe and in the USA, and that within two years a far larger *private* plant came into operation for the British Aluminium Company at Foyers in Scotland.

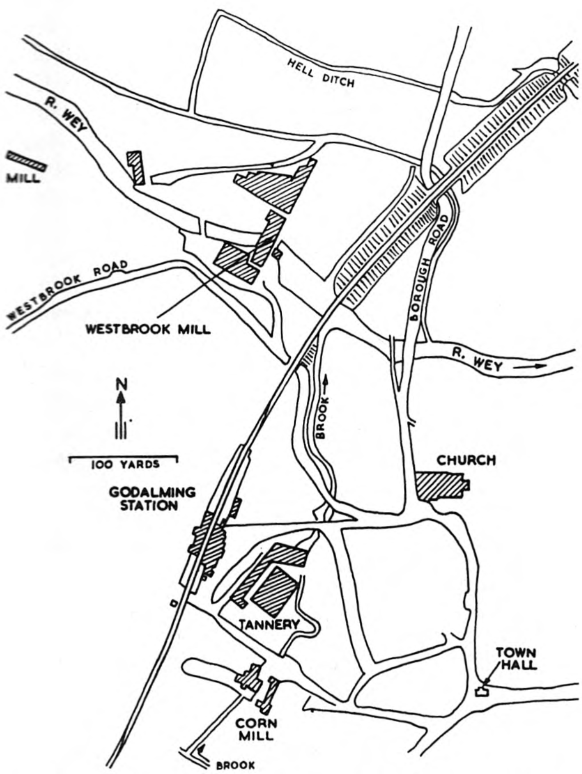
With the rather trivial exception of the short-lived Greenock installation, that at Worcester was the only one of the eight which was planned, controlled and operated by a town or city council. The others were the responsibility of private companies. The story of the Worcester station, therefore, has much in common with that of other municipal stations even though they were steam-powered, e.g. that at Bristol, opened a year earlier.[2] The lengthy dialogues with consulting engineers, the procrastination and indecision are similar. Later difficulties over providing power for electric tramways also have something in common, but the docile way in which the tramway company at Worcester accepted the council's demand that its electricity should be purchased from the council contrasts greatly with the aggressive attitude of the Bristol company, which fought, and won, a vigorous battle with the council for the right to build its own power station. But in respect of purely hydro-electric problems, Worcester's story is much the same as the others in the list and I have analysed it in some detail. More technological initiative was shown at Lynmouth, however, where what was probably the world's first pumped-storage hydro-electric system was introduced as part of an expansion programme in about 1895.

It was the general nineteenth-century experience that water power, when available, was cheaper than steam power,[3] especially in places not very close to a coalfield. It is thus not surprising that people planning a new electricity-generating station in the 1880s and 1890s should think of using water power whenever possible. Serious proposals for water-powered central stations were made in places where there was no possibility of the water power meeting even the initial needs of the station, e.g. at Bromsgrove in Worcestershire; fortunately qualified electrical engineers were usually consulted at a sufficiently early stage for such schemes to be quickly abandoned. Hardly ever was there any appreciation of the rate at which the demand for electricity would rise, and the changeover of site location at a late stage in the plans for Worcester from the large River Severn to the small River Teme illustrates this. It is no doubt fortunate that so many plans were abandoned in time. Some plans for water power were developed to a very advanced state before being abandoned in favour of steam at the very last minute, e.g. at Exeter, where the town council raised objections to the electric light company using a weir on the river. I have records of no fewer than forty-five towns in Britain where hydro-electricity was proposed during the years 1881-1894 but not adopted; the list is as follows

1881 Aberystwyth, Durham
1882 Exeter (proposal abandoned only in 1888)
1886 Lanark
1887 Cockermouth
1888 Otley, St Albans
1889 Ayr (proposal alive until 1893), Burton-on-Trent, Penrhyn, Windsor
1890 Llangollen (proposal alive until 1893)
1891 Egremont, Elgin, Helston, Hexham, Inverness, Matlock Bath, Plymouth (proposal alive until 1894), Richmond (Surrey), Shipley
1892 Barnard Castle, Bridgend, Chester, Guildford (proposal alive until 1894), Moffat, Queensferry, Reading, Rochdale, Tutbury, Willesden
1893 Bewdley, Cardiff, Crieff, Glynceiriog, Hawick, Llandrindod Wells, Montrose, Tiverton (proposal alive until 1902), Workington
1894 Baslow, Bromsgrove, Conway, Newby Bridge, Ulverston.

It is fair to say that as far as I have been able to obtain reasonably reliable data (which for hydro-electric stations is only for Worcester and Monmouth), it does seem that the idea that water-power enabled electricity to be generated more cheaply than steam-power was justified. However, in both these cases most of the civil engineering works already existed and were purchased very cheaply. Under modern conditions in Britain, hydro-electricity is more expensive than steam-generated electricity.[4]

The sources of information for this article are varied, but by far the most important are the numerous reports published in the contemporary journals *The Electrician* and *The Electrical Engineer* over the years concerned. I have made use of several hundred of these reports, and clearly it has not been feasible to cite most of them individually. Other sources, such as council and committee minute books and reports, reference books, documents generally, and private communications and interviews, are all cited as individual references where appropriate. When no source is indicated, the information should be assumed to come from one or other of the two journals mentioned above.



ig. 1 Map showing location of Westbrook Mill at Godalming nd watercourses in its vicinity, from OS Map of 1920

Godalming, 1881

The first substantial 'central station' or generating station for public distribution of electricity was opened at Holborn Viaduct in London in January 1882. Thus the little town of Godalming in Surrey (population then about 2,000) was remarkably go-ahead in having public lighting by electricity in the autumn of 1881; it is even more surprising that this electricity should have been generated from water power. Unfortunately the Godalming system was not really successful and it was abandoned in 1884 in favour of a reversion to gas lighting. It had obviously been premature; the technology was not yet sufficiently advanced and numerous other installations failed too. The failure was not basically connected with the use of water power.

Although the Godalming system is mentioned in all the books on the history of electrical engineering, there nowhere seems to be a reasonably full and coherent account—neither contemporary nor recent—of its history. Apart from the minutes of Godalming Town Council, and a few photographs, no manuscript or other archival material has been found, and so the sources are practically all contemporary printed reports, mainly in the technical press.

On 1 October 1881 it was reported[5] that:

An experiment was made at Godalming, on Monday night last, to light a portion of the town by electricity, the motive power

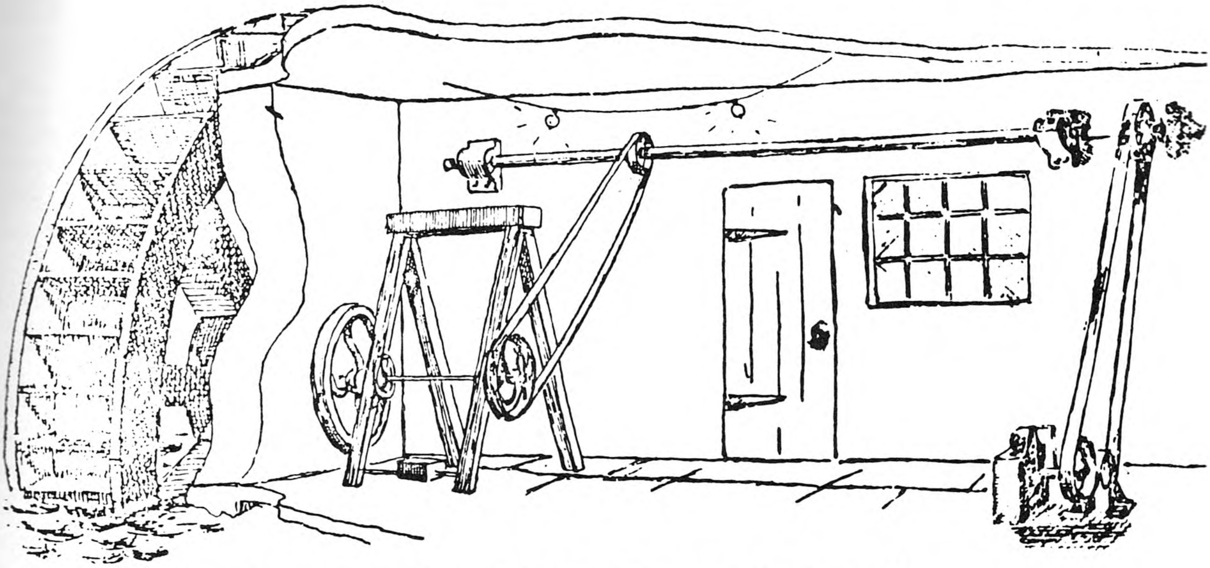


Fig. 2 The waterwheel and drive to dynamo at Westbrook Mill in 1881, from *The Graphic* of 12 Nov. 1881

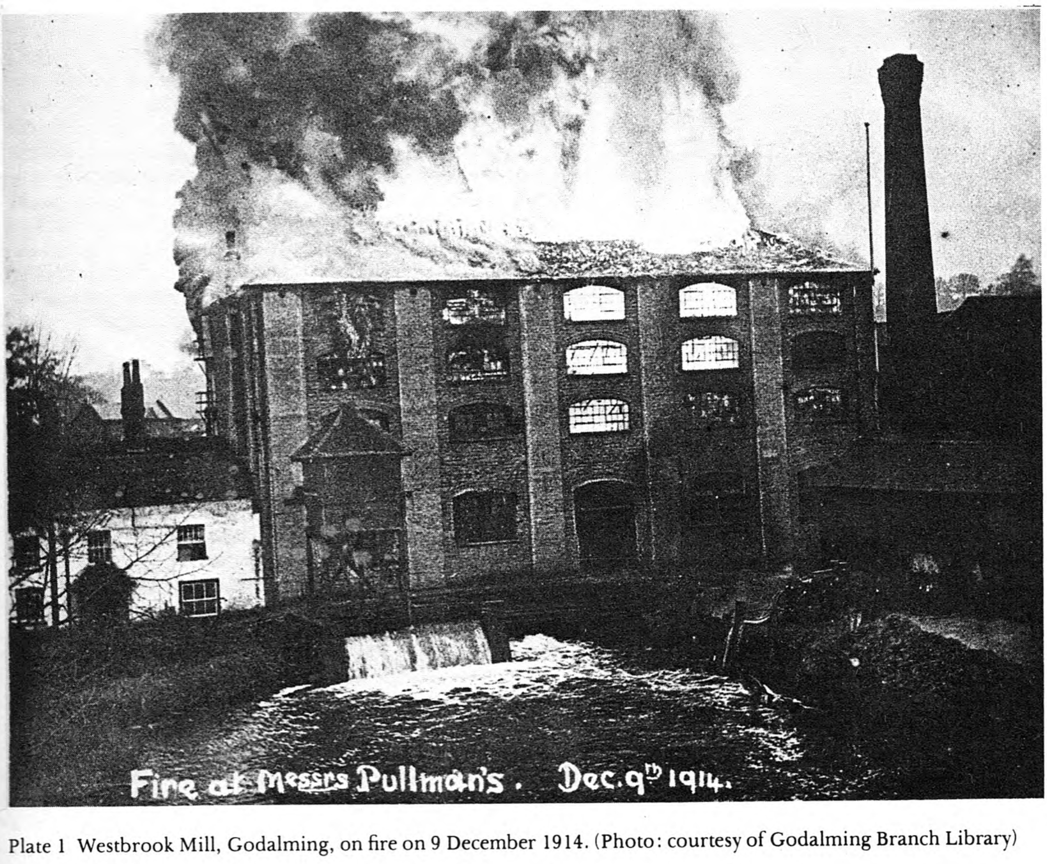


Plate 1 Westbrook Mill, Godalming, on fire on 9 December 1914. (Photo: courtesy of Godalming Branch Library)

Plate 2 Westbrook Mill in 1952 (Photo: courtesy of Godalming Branch Library)

> being obtained from a water wheel. One large Siemens lamp and several of Swan's small incandescent lights were in use, and the results were deemed satisfactory. It is proposed to fix turbines, which the River Wey will drive at considerable velocity, and so give the necessary power for supplying a number of lights for the Charterhouse Schools, Godalming, and some at Guildford also.

The location of the water wheel concerned was at Messrs Pullman's leather mill, generally known as Salgasson's Mill or Westbrook Mill, at grid reference SU 967442 (see Fig. 1). A sketch of the water wheel coupled to the dynamo (reproduced here as Fig. 2) appeared in an article[6] on 12 November 1881. Photographs of Westbrook Mill taken on 9 December 1914 when it was on fire[7] and in 1952,[8] are shown in Plates 1 and 2 respectively. It has now been demolished. It is not absolutely certain, however, that this is the building in which the dynamo was installed.

A further report[9] in December gave later information and referred to two 'turbine wheels' being used. However, a full and detailed description[10] published a few weeks later, seems the most reliable account we are ever likely to get, and we cannot do better than quote it here:

> Last September the contract with the local gas company for the lighting of the town expired, and it was decided by the authorities not to renew it, but to give the electric light a chance of showing what it could do. Messrs. Calder and Barrett undertook to install the electric light upon the understanding that the annual cost was to be less than the 200 £ a year, which was the amount of the gas contract. It was thought that by utilising the water power afforded by the Wey, this result could easily be achieved, the volume of the stream being large and a fall of some five feet being generally available. An agreement was come to by Messrs Calder and Barrett with Messrs E. and J. Pulman, leather dressers, who have exclusive rights at this point over the water power, which is used by them for driving their mills, to furnish the water power necessary for the light, in consideration of having their own mill and premises lighted up. In pursuance of this arrangement three arc lights and seven incandescent lamps are devoted to their purposes, whilst the town itself is illuminated by four arc lights and 27 incandescent. The arc lights are of fully 300 candle power, and are given by Messrs. Siemens Brothers' differential lamps, the incandescent are Swan lamps which are capable of giving off 30-candle lights. The current is supplied by a Siemens alternating current machine, working at a speed of 840 revolutions per minute, the field magnets of which are excited by an ordinary Siemens dynamo-electric machine, working at 1200 revolutions a minute, and giving off a current of 12 webers. [NB The weber was the unit of current until renamed the ampere in this very year 1881.] The alternating machine is coupled up into two circuits, one circuit being devoted to the seven arc-lights, and the other to the 34 Swan lights. The arc-light circuit has a current of 12 webers, and an electromotive force of 250 volts,

while the incandescent light circuit has a current of 33 webers, and an electromotive force of 40 volts. These two circuits are said to require 10 horse power to drive them.

It was at first thought that a single Poncelet half-breast water wheel of about 13 ft. 6 in. diameter would be sufficient to drive the machines, but it proved quite unequal to the task, and another similar wheel was coupled up with it. Together the two wheels are, in ordinary times, when the full head of water is available, just about sufficient to furnish the required power, but, unfortunately when the river is swollen by rains, the capacity of the lower channel is not sufficient to carry off the water quickly enough, and the tail-water stream rises to such an extent that the available head of water is seriously diminished and is occasionally reduced to a few inches. Under these circumstances, as the wheels utilised are wheels previously fixed and used in Messrs. Pulman's mills, and not specially adapted to the purpose for which they are now put, it has become necessary to fall back upon steam power, and for this purpose a semi-portable engine has been procured and is used as an auxiliary to the water power. In ordinary cases it is worked at a pressure of only some 25 lb., but in case of need it is equal to the whole work required . . .

The seven arc lights, which, as we have remarked, are on one circuit, seem to be almost all that can be desired in the way of steadiness and brilliancy. The four arc lights which are disposed in the town light up the main street very fairly and the leading idea of the system of installation pursued, was to illuminate the main thoroughfare, and to supplement the arc lights by the small Swan lamps for the dark corners and side alleys. This system might no doubt have been successfully carried out, despite the unsuitableness of the Swan lamps for out-door work, but unfortunately the arrangements used do not quite meet the necessities of the case. In the interior of the mill and in Mr. Pulman's house the Swan lamps are seen at their best, and the light obtained leaves nothing to be desired. In the bye-ways of the town, however, the Swan lamps, where most needed, fail to do their duty, their dull red glow contrasting, in some cases, very unfavourably with a few gas lamps which are lit. A little additional current would bring out their full glow, but from some cause or other this was not available. The chief reason of the failure of the Swan lamps in the town is simply the distance at which the source of electricity is placed from the town and the comparative smallness of the conductor. The arrangement of this conductor is worthy of remark. We have said that the whole 35 lamps are on one circuit, but this is not strictly true, and we should rather say that each Swan lamp is on a distinct circuit. One pole of the dynamo machine is connected with the ground through a convenient gas-pipe. From the other pole the conductor is led, like the trunk of a tree, from which branch off arms in various directions, these again branching off, and these again, and so on to the required extent. The conductor resembles the trunk of a tree not only in the distribution of its branches and 'twigs', but also in their gradually diminishing size, the diameters of the various branches being so proportioned as to bring into play a resistance such as will suffice to give to each lamp, as far as possible, its fair share of the current. The conducting wire itself is naked copper wire suspended from the houses by ordinary telegraph insulators, which is, we believe, a somewhat novel feature, and could of course only be adopted with electricity of low tension. Thus arranged the conductor is a tree whose root is the pole of the dynamo-machine, and which is otherwise completely insulated from the ground. If the conductor be connected with the ground at any point the circuit will be closed, the current obtained varying, of course, with the distance of this point from the machine. It thus comes to pass that the lamps in the mill and the house, which are much nearer to the machine, get much more current and burn much more brightly than those in the town half a mile off, notwithstanding that a considerable resistance is interposed in the branch which leads to the mill. This resistance is obtained by a series of carbon rods, through which the branch current passes. The necessity of interposing resistances increasing in magnitude with the nearness of the point at which the current is taken off to the source of electricity, seems one of the most serious obstacles to the adoption of this system of lighting on any but a small scale; not only from the waste involved by the resistance, but also from the inequality in burning of the lamps unless the resistances are very accurately adjusted.

The Swan lamps are arranged in the ordinary gas lamp-posts of the town. The post is made to serve as one pole, and is connected to one side of the socket into which the lamp slips, the other side of the socket being connected to the conducting wire overhead. This arrangement is at once simple and efficacious.

It is a pity that the installation has not been carried out in a way which should ensure success. With a central station, instead of the out-of-the-way place chosen, it would have been easy to arrange the system, in this small town, as to be thoroughly efficacious, and at the same time economical. As it is, we believe that the town has resolved to revert to the old system of gas-lighting, or rather, we should say, to a new and very much improved system of gas-lighting, which will give the towns-folk twice as much light as they had before. For this they have to thank the electric light and Messrs. Calder and Barrett. We believe, however, that Messrs. Pulman intend to stick to the electric light, which has served them very well, and that the Charter-house schools and grounds in the immediate vicinity are also to be lighted by electricity.

With respect to the utilisation of water power for lighting towns, the failure of Messrs. Pulman's wheels to meet the requirements of the case in this locality proves nothing . . .

Nothing more has been found in the contemporary technical press regarding what happened during the two years following this initial experience. A much later article[11] which does not cite its authorities states that in March 1882 a larger machine of 22hp was installed supplying 200 lamps of 20cp each, while in July 1882 a dc machine of 7hp was installed for lighting six street lamps, which would have been arc lamps.

Evidently the supply *was* continued, in spite of *The Electrician*'s statement of 13 January 1882 quoted above, and it was taken over by Siemens Brothers, for in the spring of 1882 they were negotiating with the town council, who would give a contract for only one year at a time.[12] There was also much correspondence with the clerk to the newly-formed Rural District Council as to what would happen under the Electricity Act of that year if the electricity supply should be extended to parts of the area outside the borough.

In 1883 the council invited tenders from Siemens, Crompton, the Brush Company, Hammond, and the Gulcher Company for a one-year continuation of the supply. Crompton and Brush declined to give consideration to any scheme based on one-year contracts. Hammond declined because he was too busy setting up the Brighton electricity system, and Gulcher had no desire to operate in the Godalming area. The gas company lowered its rates, but nevertheless Siemens got, and accepted, the contract for one year on condition that they provided a further sixteen lights.

There is some ground for thinking that water power was given up after a bad flood early in 1883; support for this comes from a reminiscence collected soon after World War I by the former librarian of Godalming from a German engineer who tended an engine in a shed at the back of the High Street,[13] and also from a remark, quoted below, made by a representative of the gas company in 1884, which refers to the electricity being then generated by an engine.

At the beginning of April 1884 the town council held a special meeting to consider future arrangements for lighting the town.[14] Four electric light companies had suggested terms, but these 'were not suitable'. Meanwhile the gas company were mustering their arguments; they had supporters on the council. They made a further reduction in their tariff, they emphasized the benefit to the town of the rates from the gasworks, and stated that their supply would be more reliable, 'the intensity of the lamps not being dependent on the instantaneous speed of an engine'.[15]

Alexander Siemens appeared in person to discuss the matter with the council, and explained that his firm was losing money in Godalming, and could not contemplate continuing unless they had a long-term agreement which would make it worthwhile investing in expansion and re-equipment. The council were sympathetic, although legal difficulties were discussed, but before anyone could proceed it was evidently necessary to canvass the town to see what prospect there was of more business. Siemens undertook to do this.

Later in April[16] it was reported that the results of the canvass had been unsatisfactory, and accordingly the contract with Siemens Brothers would terminate on 1 May 1884 and the town would revert to gas:

> The gas company have, however, been wise in their generation, and have reduced the price of gas, whilst they have also improved its quality. Whereas three years ago they charged £5 5*s*. for each street lamp burning 5 feet per hour, they have now reduced the price to £4 per lamp, and have fitted them with 6ft burners. Godalming should, therefore, have Messrs. Siemens Brothers & Co. in grateful remembrance.

There was much argument[17] about electric light in Godalming in the years after this, especially 1890-99. Finally the town council gave up trying to decide whether or not to set up an electric lighting undertaking, and transferred the Provisional Order which they had obtained in 1896 to Edmundson's Electric Corporation in 1899. It is believed that the new electricity works were eventually opened in 1901, i.e. after a gap of seventeen years. They did *not* use water power.

Greenock, 1885

The town of Greenock, in Renfrewshire, obtained a Provisional Order in May 1883 under the Electricity Act of 1882, and was thus one of the first in Scotland to be authorized to develop an electricity supply.[18] It was certainly the first town in Scotland to generate electricity for public supply by the use of water power, and the second in Britain. Unfortunately, Greenock's system, opening on 9 March

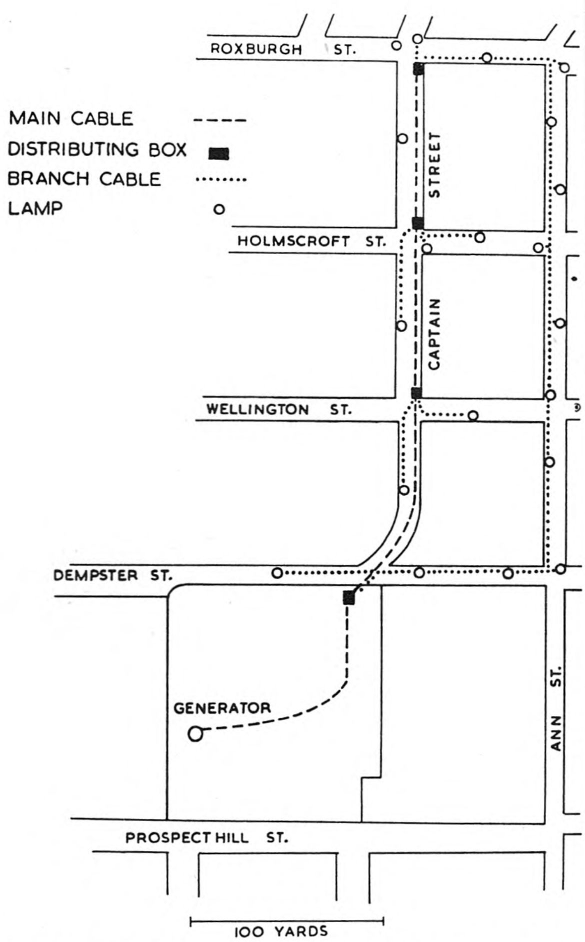


Fig. 3 Map showing the location of the generating station at Greenock and the lighting distribution, based on *Engineering*, **40**, 1885, p. 50

1885, was also short-lived, as it closed in May 1887. In fairness, it must be stated that it was introduced as an experimental installation; it attracted interest at the time, not because it was water-driven (this fact was barely mentioned), but because it used a novel type of underground cable.[19]

The initial steps appear to have been taken in October 1881, when the Greenock Police Board, which had responsibility for public lighting, resolved to promote a Bill in Parliament to obtain powers for lighting the town by electricity.[20] It is possible that the Board were stimulated to this resolve by the action of the Greenock Harbour Trustees, who had at this date reached the stage of inviting tenders for the electric lighting of a portion of their harbour, quays and sheds.[21]

The first mention of the use of water power seems to have been at about the time the Provisional Order was granted, for in June 1883 it was reported[22] that a special sub-committee of the Law and Finance Committee had submitted a report to the Greenock Police Commissioners stating that they proposed to make representations to the Board of Trade, asking, *inter alia*, that the water power of Greenock might be utilized. At the same time the Commissioners also considered a report by Mr. S. Stewart, the manager of the gasworks, giving an estimated cost of the 'proposed experiments within a limited area in the Sixth Ward':

The area, it was stated, was bounded by Prospect Hill, Ann, Roxburgh and Mt. Pleasant-Streets. The length of streets in the area was about 3600 yards, and the power for lighting would be got from the Water Trust Premises at Prospect Hill. Mr. Stewart proposed to put up only eight arc lamps in the meantime, if the arc system were adopted, at a total cost of £1000. He, however, recommended the incandescent lamp, and 90 to 100 such lamps fitted on the existing gas lamp-posts, together with every accessory, he estimated to cost £1000.

The expenditure of £1,000 was authorized.

Tenders were invited for undertaking the installation, and seven offers were received in mid-1884.[23] Siemens declined to offer. Several offers were unsatisfactory in that they gave no details, others in that they did not comply with the specification. The satisfactory offers were

Anglo-American Brush Electric Light Co	£911
Muir & Mavor	£943
E. Beckingsale	£1,040

These were surprisingly close to Mr. Stewart's estimate of £1,000.

The Electric Lighting Committee decided that Professor Jamieson of Glasgow should be consulted over these offers. He also acted as consultant throughout the 'experiment'. He evidently thought that Beckingsale's offer was the most satisfactory, for this was the one accepted, the contract being signed in October 1884.

The work was completed and the installation put into service on 9 March 1885. Professor Jamieson had supervised the installation of the equipment and cables, and tested them himself, finding them entirely satisfactory.[24] There were twenty street lamps in the area, which is shown in Fig. 3. The grid reference of the generator site is NS 273757. There were three lamps in the machine-house and grounds, and electricity was also supplied to the Roxburgh Street Refining Company to light their char-house with about ninety lamps.

The total cost had worked out at £1,751.57½, made up as follows:

1	Beckingsale's contract	£873.46
2	Six months' maintenance by Beckingsale	73.00
3	Cost of machine-house, trenches, etc.	386.37½
4	Turbine pulleys and gearing	151.50
5	Consulting engineers	51.00
6	Cost of Provisional Order and printing	216.24

At the end of Beckingsale's six-month maintenance contract, two men were engaged to attend the machinery at a total cost of £2.50 per week.

The dynamos used (probably two in number) were Anglo-Brush Victoria machines, driven by ropes from a Gunther turbine.[25] W. Gunther had set up business as a turbine-maker in Oldham in 1881, and this was his turbine no. 12 of 1884; it was of the Girard type, of 40hp.[26] The lamps were of Swan incandescent type. Distributing boxes were placed at intervals in such a manner that the system could be extended at any time with little trouble and without interrupting service. Lead-coated wires made by the Kinetic Engineering Co. were used, all laid underground.

Although the 'experiment' was evidently considered successful during 1885, it did not continue long. The reasons were not given when, after Greenock returned to electricity in 1900 (this time steam-powered), an article[27] on the new installation referred to the earlier installation merely as 'not very successful'. An unsigned note in the *Electrical Review* for 24 June 1887, commenting on a vague note in the issue for 27 May, stated that the closure was solely due to the heavy charges for lamp renewals.

Wickwar, 1888

The public lighting of the little town of Wickwar, in Gloucestershire (population about 1,000) was not a very ambitious undertaking and was only an offshoot of a private hydro-electric installation put into operation during the winter of 1887-8 by Messrs. Arnold, Perret & Co. Ltd., at their brewery at Wickwar. The prime purpose of the installation was to light the brewery—quite a large one—with about 100 incandescent lamps. Finding there was surplus power available, the firm offered the town an electricity supply, which was gladly accepted. The public lighting began on 2 October 1888 with 15 lamps, each of 32 candle-power, the furthest being three-quarters of a mile from the generator. The distribution was at 200V using bare wires on poles, and the lamps were arranged in pairs, the two lamps of each pair being connected in series across the 200V feeders. The Phoenix Fire Office rules were carefully observed throughout.

The motive power was an overshot water wheel of 36ft. diameter; the dynamo was a shunt-wound machine by Elwell & Parker, running at 550rpm. All the installation work was done by local men under the direction of F. Graham Ansell, a professional electrical engineer.[28]

By its fourth winter the system had been extended to twenty public lamps covering over a mile of road, and the town paid £15 pa for this.[29]

The location of the generator was probably at grid reference ST 726 890, opposite the brewery, where the contours of the land are such that a small stream was able to supply a pond and provide the water wheel with the 36ft head required.

Okehampton, 1889

Like the system at Wickwar, public electricity supply at the town of Okehampton in Devon (population around 3,000) was an offshoot of a private installation. Mr. Henry Geen (who became the principal of the firm of Blatchford, Ash & Company) was a builder and timber merchant in quite a large way of business, and had installed a turbine to drive the machinery of his sawmill, using water from the East Okement river.[30] He also coupled to the turbine a 110 volt dc dynamo of the Crompton two-pole overpole type and used the electricity to light the sawmill and possibly also to drive some motors.

In December 1888 it was announced:[31]

> The public supply of electricity upon a very limited scale is about to be undertaken at Okehampton by Mr. Henry Geen. Water-power is available to the extent of about 125 incandescents . . . and since gas costs 5*s.* 10*d.* per thousand [cu ft] in Okehampton the economic conditions are evidently favourable. Several houses in the town are now being wired, and arrangements are being made to lay the wires underground.

In March 1889 it was announced that the system had proved successful and that the gas company now wanted to supply electric light![32] Six weeks later it was announced:[33]

> The directors of the Okehampton Gas Company have summoned a meeting of the shareholders at which it will be proposed to apply for powers to lay cables to enable the company to supply the electric light and to raise additional capital.

Evidently nothing came of this proposal, and in a table of electric central stations for 1890, Okehampton was entered as still under H. Geen, with a low-tension supply, capacity 220 8cp lamps. This was not much more than about 8kW.

Geen's supply scored a 'first' when a new Baptist chapel, built by Geen with a seating capacity of 400, was 'the first village chapel in the south-western counties in which the electric light has been adopted'.[35]

The demand on Geen's public supply grew, and in 1896 he supplemented the water power with a 50hp Worth-Mackenzie compound tandem vertical condensing steam engine supplied by a Babcock & Wilcox water-tube boiler which was fired mainly by wood refuse from the sawmills blended with steam coal. This was later replaced by a 30hp Crossley suction gas engine and suction gas plant. After World War I two 60hp Gardner petrol-paraffin 4-cylinder direct-coupled generating sets were bought from the War Office. Still at the sawmill, and providing about 110kW, this plant was taken over by the West Devon Electricity Supply Co. in 1930, and eventually dismantled when their new Mary Tavy hydro-electric station was opened in 1937. (This was, and remains, England's largest hydro-electric installation, although its installed capacity of 2.6MW is small by Scottish and Welsh standards.) Whether the turbine at Okehampton continued to contribute to the generation of electricity right up to the end of the Okehampton plant is not quite clear.

In the early 1920s the Okehampton Town Council was negotiating with the proprietor of the generating station (then shown as G. K. Blatchford, presumably a partner of Geen's) for the purchase of the undertaking.[36] Evidently these negotiations came to nothing, and in 1925 the works were owned by W. G. Heath & Co. of Plymouth, the manager being W. Leigh who had been manager under Blatchford.[37]

The weir on the East Okement river still exists, at grid reference SX 590951, and the buildings are at SX 590952.

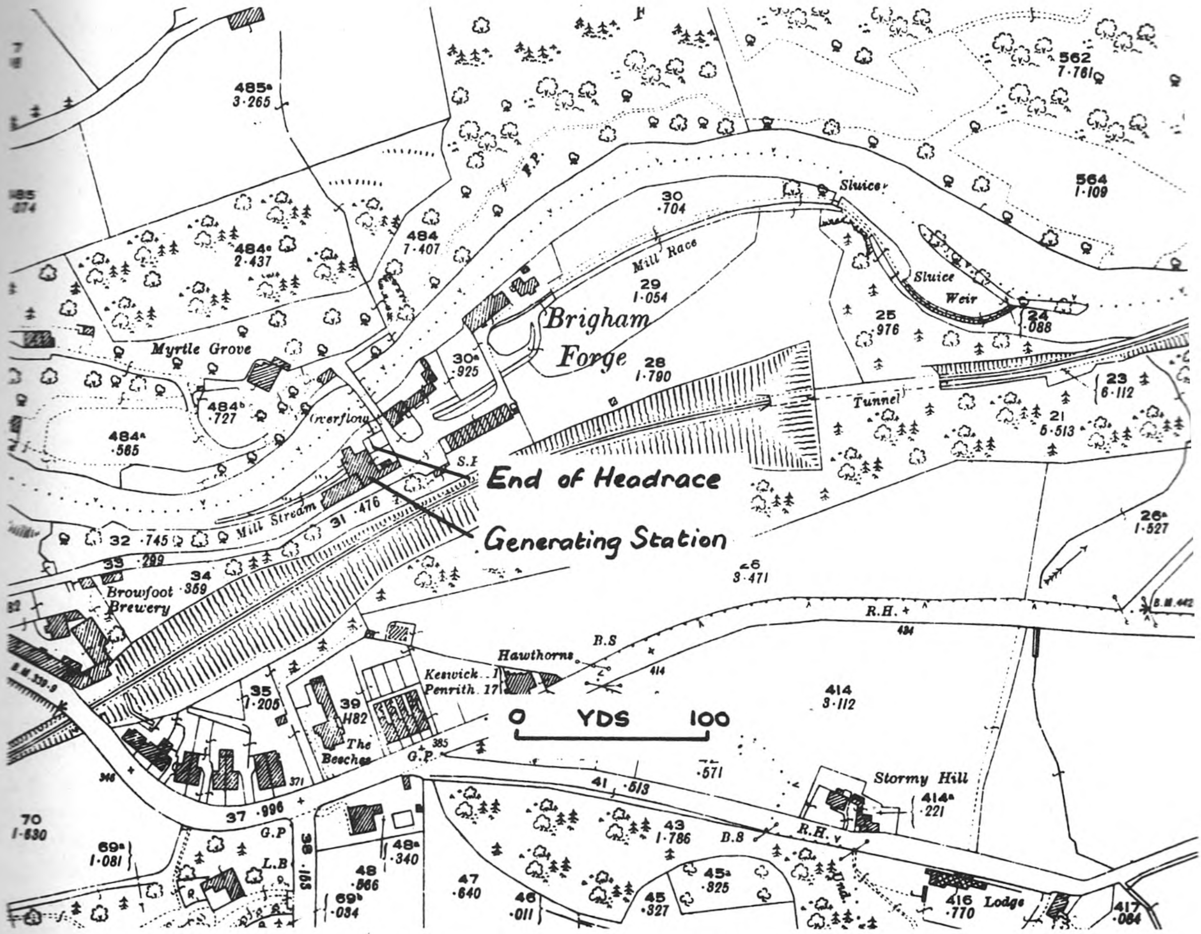


Fig. 4 Layout of the site of the Keswick electricity generating station, based on the 25-inch OS map of 1924

Keswick, 1890

A paper[38] on the Keswick system in the *Proceedings of the Institution of Civil Engineers* in 1890 described it as 'the first attempt to utilize available water-power in this country for the purposes of a public supply of electric light', but this was in error, as we have already described four earlier installations; these were, however, a good deal smaller, and it would probably be fair to describe the Keswick system as the first substantial one. It operated at first without parliamentary authority.

The Electricity Act of 1888, by amending unwise provisions in the earlier Act of 1882, made it attractive, for the first time in Britain, to invest in electricity supply systems for the lighting of streets and public and private premises. Thus, what is usually termed public supply developed rapidly from about 1890 onwards. The procedure was for a company or municipality to obtain a Provisional Order under the Act, which enabled them to break open streets, etc., for the purpose of laying mains and other underground equipment. Companies which for one reason or another wished to proceed without a Provisional Order were forced to adopt overhead distribution, or to use subways and tunnels provided for other purposes, or to lay cables only on private land. It is interesting that the Keswick Electric Light Co. operated on this basis for the first eight years of supply at Keswick.

As at April 1973 the building which housed the generating station still exists, but it is understood that it is not likely to remain much longer.

The main sources of information about the system are the journal *Electrical Engineer*, which published twenty-seven short reports on the subject over the years 1889-98; the paper in the *Proc. Inst. Civil Engrs*, already referred to; a most useful interview with a former employee of the company, Fred Armstrong; and physical investigation on the site.

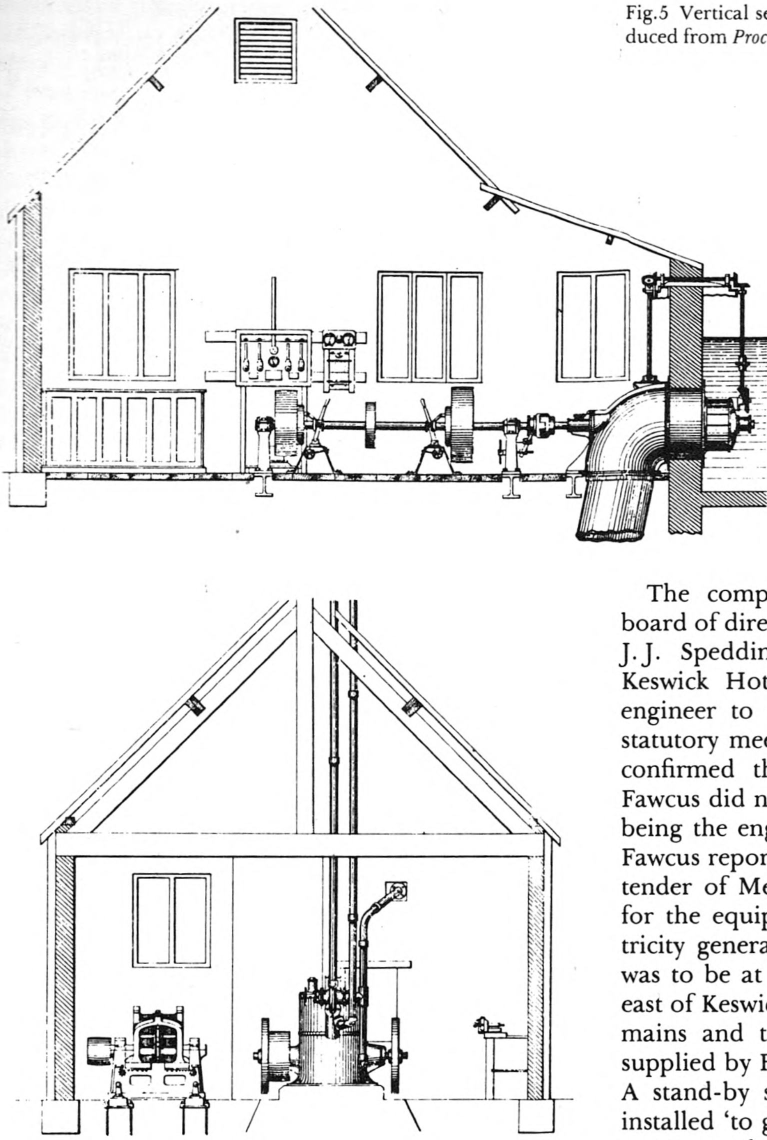


Fig.5 Vertical sections of the Keswick generating station (reproduced from *Proc. Inst. Civil Engrs.*, **102**, 1890)

Unfortunately, the minute books of the Keswick Town Council for the period concerned appear to have been lost; they might have given useful information about the negotiations between council and company. All information may be assumed to come from the *Electrical Engineer* unless otherwise indicated.

On 22 February 1889 it was reported that:

Steps are being taken to form an electric light company at Keswick, the project having the support of several of the most influential residents. A survey has been made, and it is expected that the works will be on the banks of the Greta, the river supplying the motive power. A prospectus will be issued to the public shortly.

The company was started with a provisional board of directors which comprised R. D. Marshall, J. J. Spedding, Dr. Knight, W. Wilson (of the Keswick Hotel), and W. P. J. Fawcus (consulting engineer to the company). On 1 August 1889 a statutory meeting of the company was held which confirmed these appointments, except that Mr. Fawcus did not wish to be a director in addition to being the engineer and was replaced by J. Birkett. Fawcus reported that the directors had accepted the tender of Messrs. Johnson & Phillips of Charlton for the equipment of the central station (as electricity generating stations were then called) which was to be at Forge on the River Greta, just to the east of Keswick, and for the supplying and laying of mains and transformers. The turbine was to be supplied by Frederick Nell of Mark Lane, London. A stand-by steam engine and boiler were to be installed 'to guard against the contingency of short water supply or other exceptional causes'. It was expected to have everything ready by 1 October. Johnson & Phillips would run the station for one month after completion before handing it over to the company, 'and then it has to be subject to the entire satisfaction of the company's engineers'. The Keswick Urban Authority passed the plans in August.

The opening was a little behind schedule, being on 7 January 1890, but otherwise all went well, and no hitches were experienced. The work had been supervised by Fawcus's partner, Mr. E. W. Cowan.

The station was built near Brigham Forge, on the site of an old woollen mill (grid ref NY 280240). The weir, and head and tail races, which had originally

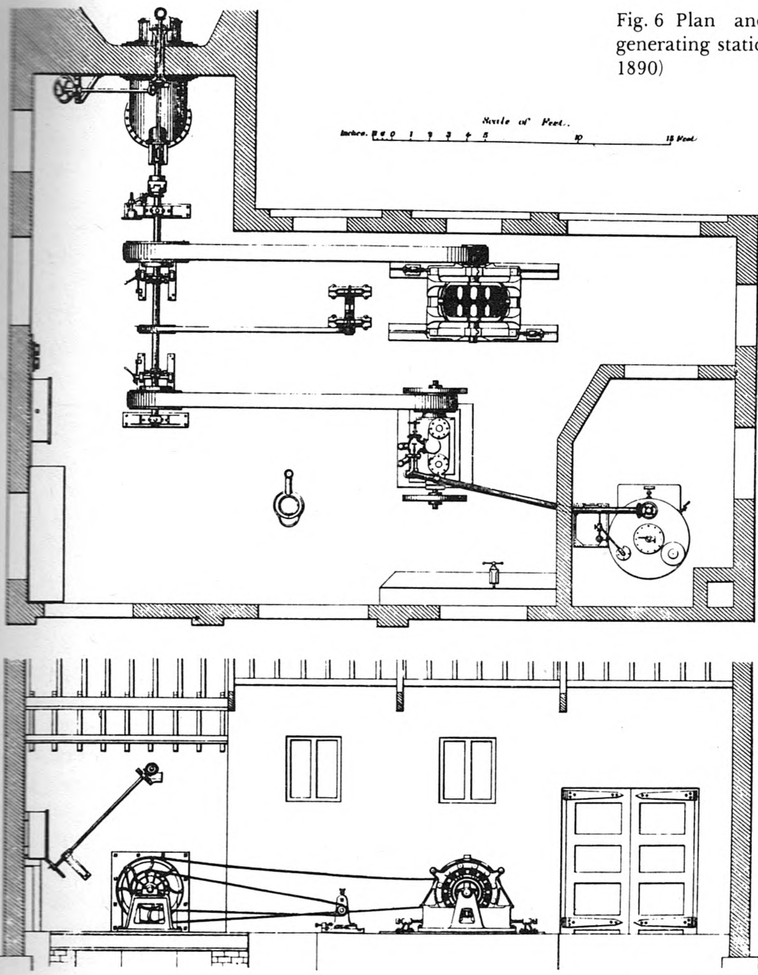


Fig. 6 Plan and another vertical section of the Keswick generating station (reproduced from *Proc. Inst. Civil Engrs.*, **102**, 1890)

been provided for the mill formed the basis of the power supply for the electricity station; but in order to increase the head of water to 20ft, the tail race was lengthened from 70 to 100yd and deepened by 4ft. The head-race was improved a little by increasing its cross-section to 7ft width by 3ft depth. The new building was serviceable rather than handsome. The site arrangements are shown in Fig. 4.

The single 'Victor' horizontal turbine of 50hp, supplied by Frederick Nell of London, was built into the end-wall of the head-race which served also as the wall of a bay of the station building, as can be seen from the vertical section in Fig. 5 and the floor plan in Fig. 6. The stand-by steam engine, also of 50hp by Westinghouse, with two 10in single-acting cylinders and 9in stroke, drove on to the main shaft, and clutches provided for the alternator to be driven by either the turbine or the engine or by both together. The alternator was a 30kW machine to a design by Gisbert Kapp,[39] giving 15A at 2000V at a speed of 750rpm. The frequency was 75 cycles/sec (or Hz).[40]

The turbine had a wheel diameter of 20in, and was of the mixed-flow type which had a high speed compared with other low-head turbines (actually 275rpm) and thus simplified the drive to the alternator and the matching of speed with the steam engine (which ran at 350rpm). As the turbine was fitted at head-race level, a draught tube was necessary to couple it hydraulically to the tail race, and this was of wrought iron, 14ft long and 3ft in diameter. The speed of the turbine was regulated by hand.

The mains were chiefly overhead wires with light insulating covering, relying for insulation from each other and from earth rather more on Johnson & Phillips's oil-insulated supports than on their covering. Care was taken with the lead-in arrangements to buildings. A generous conductor size was used so that the voltage drop in the mains was small (about one per cent) and the voltage at the consumer's premises, therefore, little affected by the load. Wooden poles about 200ft apart and steel suspension wires were used.

One short run of underground cable was provided, using the Brooks oil-filled iron-pipe system, which was later used successfully in a number of important electricity undertakings, notably that concerned with the hydro-electric system at Worcester.

Although the main distribution was at 2000V, the supply to individual premises was at 100V, twenty-two transformers being fitted at various locations to step the voltage down. Switches were provided on the high-tension side of all transformers, and watertight cast-iron cases were provided for transformers and switches.

By March 1891 the directors of the company were complaining that the demand for light exceeded the means of supply. There were now 705 lamps connected, including one arc lamp of 500cp. This would not normally be a matter for complaint by the supplier, of course, but the company were chronically short of capital. They had managed to raise another £1,000 since October 1890, but they still had £1,645 of shares which they could not dispose of. They announced that they had added a second alternator to the station and intended to install a second turbine. It is fairly certain, however, that this was not added for some years, and in the meantime the steam engine had to be used, with consequent high expense of working.

A year later the company was complaining of the cost of using the steam engine and of the lack of benefit they were receiving for their outlay on extensions to the mains. However, out of receipts of £541 they made a small profit of about £87 (they had made a profit of £34 in the first year) and paid a dividend of 3 per cent.

By March 1894 they were making a loss—about £70 in the last year. Their total subscribed capital was £3,420. They badly needed more capital, and were drawing up plans for new equipment to which they hoped the shareholders would make a ready response. They had 'confident expectations of being able very soon to use the whole water power of the river, without which success is impossible'.

Ever since 1891 there had been complaints about the unsightliness and danger of the overhead distribution system. By the end of 1894 the company were asking for a Provisional Order so that they could lay underground mains in the streets. 'The company have hitherto distributed their light

Plate 3 The building of the Keswick electricity-generating station from the tail-race. The extension which housed the Gunther turbine is on the left. The building on the right played no part in electricity generation, and was used for the manufacture of soya flour during World War II. (Photo by D. G. Tucker)

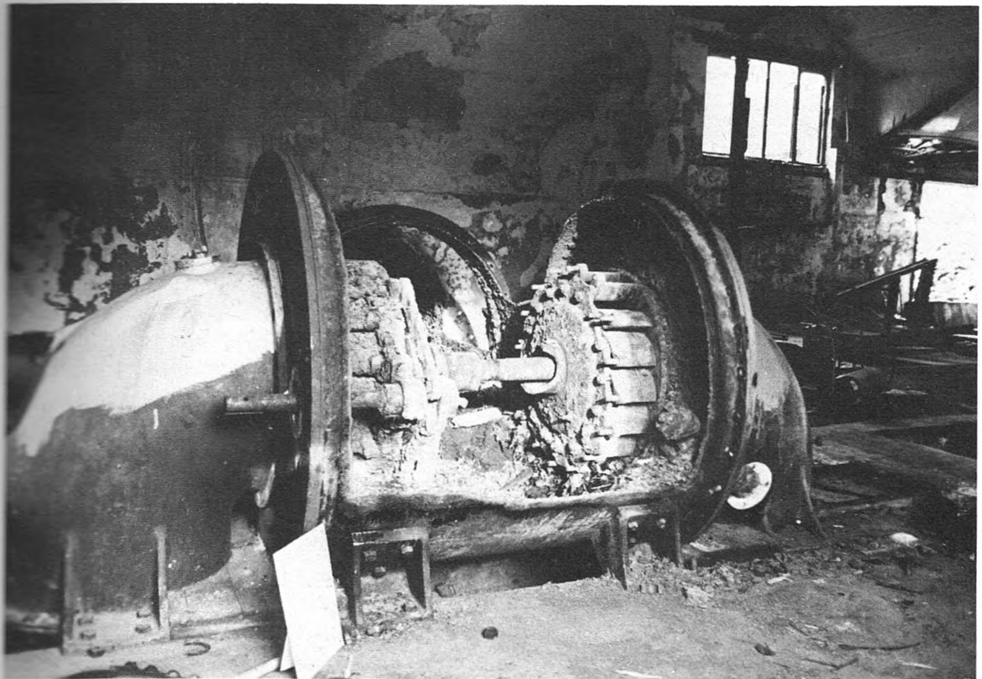


Plate 4 The remains of the Gunther turbine at Keswick. The white plate leaning against the left-hand end of the turbine is 13 inches high (Photo by D. G. Tucker)

principally by above-ground wires and on sufferance, and now wish to obtain a legal status, with right to lay mains under the streets and other privileges and duties.'

The process of getting a Provisional Order did not go smoothly. In February 1895 it seemed that the Keswick Town Council would support the company's application, but in March and April it became clear that they were hesitating and proposed to call a meeting of ratepayers to discuss the situation. The company said it would have to wind up if it could not get support. Things moved slowly.

In February 1896 it was announced that the council and the company were separately asking for Provisional Orders. By April it was known that the company was unsuccessful and that the council were given the Order.[41] The council then, in June, offered to purchase the company's works for £2,000. The company made a counter-proposal that the council should hand over the working of their Order to the company on certain terms, which included a substantial expansion and renewal of plant and an agreement to sell the undertaking to the council in $5\frac{1}{2}$ years' time on a specified basis. There was, however, repeated delay in reaching a decision, discussion in council was very acrimonious and stormy, a committee of five was appointed to consider the matter and then in October the council asked the company to send two representatives to meet two representatives of the council. Agreement was at last reached in December 1896 when the council offered the company the Provisional Order on certain terms which were quite reasonable and modest and which included the right of the council to purchase the undertaking at any time after the expiry of forty-two years.

It was now the turn of the company to drag their feet. They did not move to take over the Order. In May 1897, at a council meeting, 'Mr. Bromley thought it was a pity that a little electric fluid could not be inserted into the workings of the directorate of the company'. The council now felt free to offer the Order elsewhere and appointed a committee to deal with the matter; this, in September, advertised for the purchase or lease of the Order. Perhaps there were no takers, for in January 1898 the company gave acceptance to the council, and by June 1898 the final decision was made for the transfer of the Order to the company for forty-two years.

The following year the whole of the shares and debentures were acquired by the Windermere and

District Electric Supply Co.,[42] but the Keswick Electric Light Co. continued as a separate entity, under that name, until the system was closed down finally in January 1940.

Almost immediately on accepting the Order, the company replaced the old overhead lines by 2000V concentric paper-insulated, lead-covered, tape-armoured underground mains which remained in use until 1938 when a supply of electricity was obtained from the Central Electricity Board.[43]

In 1900, the company were charging 6*d*. per unit for lighting. The 'unit' was the Board of Trade unit of kWh as used today. Evidently meters were being used at the consumer's premises.

It has proved difficult to obtain any reliable and consistent picture of plant developments before 1924. In that year Mr. Fred Armstrong, who still lives in Keswick, entered employment with the Keswick Electric Light Co. at the generating station and remained there, as an engineman, until its closure in January 1940. His information about these later years is reliable. Standard sources, such as the annual tables in *The Electrician* and in Garcke,[44] are inconsistent and contradictory, and must, therefore, to some extent be erroneous. They also conflict with the information given by Swale.

It is certain that a Gilkes 50hp vertical-shaft single Vortex turbine was supplied in 1898 and probably replaced the original Nell machine.[45] By 1909 there seems to have been a second turbine, and this may have been the Gunther 85hp turbine (made by W. Gunther & Sons of Oldham) which was certainly installed at some time before 1924; to accommodate this a small extension of the building was built on the side facing the river. Around 1928 the earlier turbine (presumably that by Gilkes) was replaced by a larger one, of 85hp.

The original steam-engine was apparently replaced around 1900 by two Brush steam-engine/alternator sets which had become redundant at Windermere; one was rated at 25kW and the other at 100kW. Garcke's Manual shows a Parsons' steam turbine among the plant in 1902, but this is most unlikely to be true. One steam engine remained in the station to the end, but was rarely used after diesel engines were installed. These comprised one of 165 BHP with an 80kW alternator, installed around 1927, and one of 200 BHP installed in 1934, both made by Mirrlees. The former was a 3-cylinder engine, and the latter a 6-cylinder.

The company always tried to use the water power to the full. Although the weir did not stretch across the whole width of the river, they did manage to get most of the river water by building up a rough weir of boulders across the further section of the river's width. They often had some complications owing to the practice of the water-driven bobbin mill half-a-mile further up the river closing down on a Saturday morning; the water supply to the electricity station was then largely cut off until the head-race at the bobbin mill filled up and water overflowed the weir above the mill.

Present remains

The building itself remains, in a rather dilapidated condition (see Plate 3). The only significant equipment remaining is the Gunther turbine (see Plate 4), from which the casing has been cut away for scrap. As can be seen, it was a double-ended turbine with the inflow at right angles to the turbine shaft through the pipe of 3ft 6in diameter seen in the wall of the building. The head-race (Plate 5) remains in good order, but now overflows into the river a few yards above the station. The tail-race is partly filled in, but a good stretch still remains as built, as seen in Plate 6.

Lynmouth, 1890

The water-powered electricity-generating station at Lynmouth in Devon was opened in March 1890, only two months behind that at Keswick. It was, however, a larger and more interesting station, for within a few years it was using both reaction and impulse turbines, it had five separate turbines, it had a pumped-storage system with the remarkable head of 760ft, and if it did have a supplementary steam-engine drive, this was certainly not provided before the very end of the nineteenth century. Like the Keswick system, the electricity distribution was done without the benefit (and bother!) of a Provisional Order under the Electricity Act of 1888. The station endured, with its alternating-current supply at 100Hz (or cycles per second), until the great floods of August 1952 virtually destroyed it.

The sources used for this history are, in the main, printed ones, comprising about twenty-five progress reports in the contemporary journals *The Electrician* and *The Electrical Engineer* over the years 1889-1900; an account of the installation contributed by Mr. Mordey (the designer and supplier of the alternators used) to a discussion on the Keswick installation;[46] a technical description of the system as at 1899 by Mr. Bale, the General Manager and Engineer of the company;[47] the annual volumes of E. Garcke's *Manual of Electrical*

Plate 5 The head-race at the Keswick generating station (Photo by D. G. Tucker)

Plate 6 The tail-race at the Keswick generating station (Photo by D. G. Tucker)

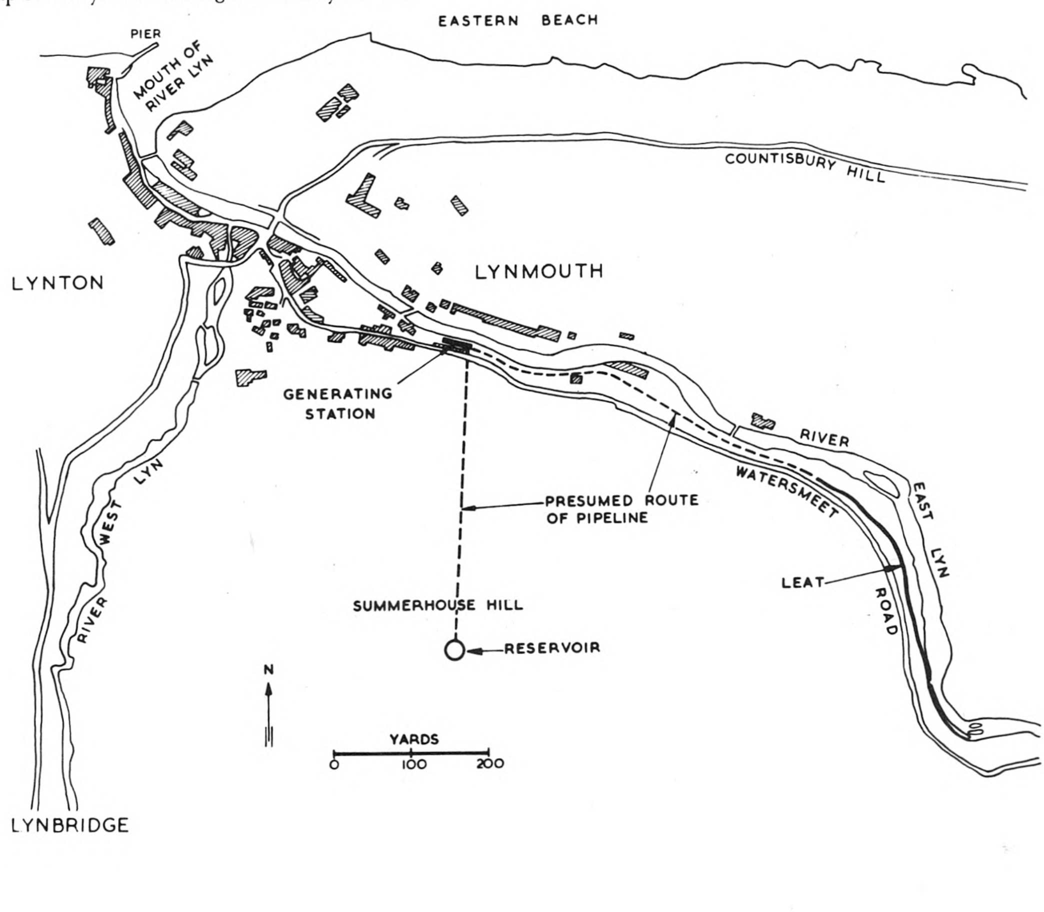
Undertakings, which commenced in 1896; reports on the effects of the 1952 floods;[48] and a note on the pumped-storage system.[49] It would have been useful to have had access to the minute books of the Lynton Local Board of Guardians for the years around 1890, as these would have given information on the negotiations between the Board and the Electric Light Company, but unfortunately they are neither in the Lynton Council Offices nor in the Devon County Record Office and must be presumed lost. For more recent years a most valuable source of information has been Mr. T. Brookhouse, who was engineer-manager at the Lynmouth generating station for many years up to 1948; he has been very helpful in answering questions. Dr. R. Ferrer of Lynton has also been helpful; to both these gentlemen I am much indebted.

It should be explained that Lynmouth is a small town at the confluence and mouth of the Rivers East Lyn and West Lyn, and is administered jointly with Lynton, another small town adjacent to it but on the cliff above it. The literature refers indifferently to Lynmouth, Lynton or both.

The initiative for the provision of an electricity supply and electric lighting in Lynmouth and Lynton was taken effectively by a private individual, a Mr. Charles Geen (often referred to in reports as Mr. Green, and a brother of the Mr. Henry Geen who had set up the electricity station at Okehampton), who formed the Devon Electric Light Co. early in 1889 and proposed a system which included the lighting of the public places, streets, etc., of the twin towns. In August 1889 the Lynton Local Board accepted his terms, and the work went ahead. The 'Lynmouth Central Station' (as it was called by *The Electrician*) was opened in March 1890.

The generating plant as initially installed was simple enough. The water power was obtained from the East Lyn river by way of a weir, then an open leat, 6ft wide by 3ft 6in deep, for the first 400 yards, and finally a 30in iron pipe for 520 yards to the station (see Fig. 7). The head at the turbine was about 90ft; Mr. Mordey said 95 and Mr. Bale said 87.78! A horizontal-shaft reaction turbine of the 'Little Giant' type was used, made by Hett of Brigg

Fig. 7 Map of the hydraulic arrangements at Lynmouth.



in Lincolnshire; it could develop a power of around 150hp. It had a draught pipe into the tail race. Regulation was by hand-wheel control of a slide valve controlling the flow of water. Two Mordey alternators were driven by the turbine on a single shaft, as shown in Fig. 8; each could develop about 37.5kW at 2000V. They had stationary armatures and rotating field coils. The high-voltage distribution was by Callender's bitumen-covered, lead-sheathed cables laid underground, some directly, but mostly in bitumen-sealed wood casing. Transformers were used to step the voltage down as required.

The service given by this initial installation was not all that could be desired. Although Mr. Mordey had earlier stated that 'Mr. Geen took great pains with the cables, and had experienced no trouble', yet we find the following report in February 1891:

> The electric light, which has been entirely absent from Lynton and Lynmouth since Christmas, reappeared at Lynmouth last week, and has been satisfactory there, but has failed to reach Lynton. An electrical engineer has recently tested the wires, and reports that the joints are in a very defective state. The matter is being attended to with all speed.

Little blame can be attached to Mr. Geen, of course, because power cable technology was in its infancy. He had had the joints 'boiled in pitch *in situ*, and then protected by soldering a lead sleeve over all', and undoubtedly had taken great pains with his installation. The light was satisfactorily restored to Lynton by the beginning of March.

In January 1892 it was reported that 'the electric light is rapidly becoming appreciated in Lynton and Lynmouth'. The light was installed in the Devon and Cornwall Bank and in the bank manager's residence, this being the first private house in the area to use it. The surveyor to the Local Board gave a very satisfactory report on the electric light in June 1892. Business expanded, and by September 1893 complaints were being made that the company could not meet the demand for electricity, especially when the water flow in the river was low. Pressure was put on the company to install more machinery.

Geen sold his company to H. H. Benn at the beginning of 1892. Evidently the growth of demand put Benn in some difficulty, and in October 1893 he suggested to the Local Board that they should take over the undertaking at a rental of £193 per annum. They declined to do so, however, and by December 1893 Benn had to refuse to take on any more business as his plant capacity was fully taken up. By the end of April 1894 he had sold out to a new company, the Lynton & Lynmouth Electric Lighting Co., who were stated to be prepared to generate more power and thus give a more efficient service. The Local Board promised that if they were satisfied that the new company could meet the demand,

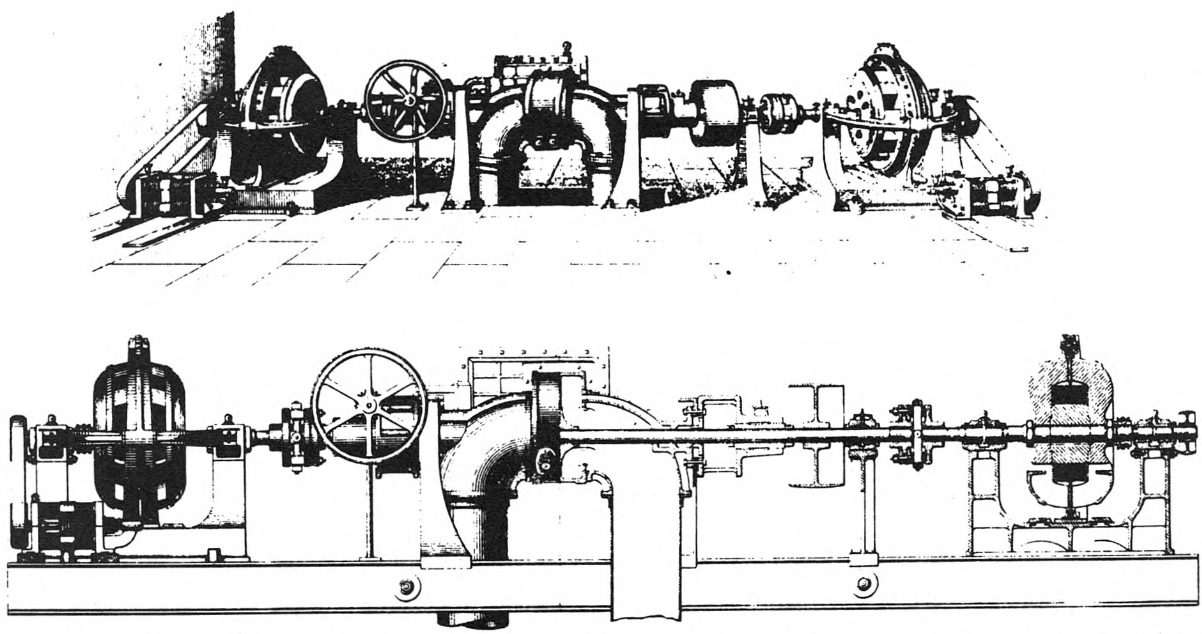


Fig. 8 General view and diagram of equipment in Lynmouth generating station in 1890 (reproduced from *Proc. Inst. Civil Engrs.*, **102**, 1890)

they would extend the public lighting contract to the new company for fourteen years.

The new company's plans included not only new turbines and alternators, but also a pumped storage system. Evidently they were able to provide a new injection of capital into the system. Where the money came from is not clear; the only directors in 1896 were Benn and Geen, the latter being managing director up to at least 1923. So, although the company changed legally, the management never changed.

Pumped storage

The Lynmouth pumped storage system may well have been the first in the world used in connection with electricity generation. We cannot do better than quote reference 49, written in 1955:

> . . . the load on the station was becoming greater than the plant could supply, and moreover the owner of a flour mill some miles upstream persistently interrupted the water supply at the period when the demand was heaviest. The company operating the power station therefore decided to install a pumped-storage scheme. During periods of low demand, surplus electrical energy generated by the water turbine was used to operate a pump made by Bailey's (the predecessors of Sir W. H. Bailey & Co. Ltd.) which lifted the water through a pipeline to a storage reservoir at Summer Hill, some 800 ft above Lynmouth. The reservoir capacity was 190,000 gallons, and as it still exists it may be stated, in the present tense, that it is 50 ft in diameter with a depth of 16 ft 6 in at the outlet side. When the peak demand developed, the water in the reservoir was fed back through the pipeline to operate a 50 h.p. Pelton turbine.
>
> This pumped-storage system, which was installed so long ago, continued to operate until as recently as August 1952, when the station was destroyed by the tragic floods of that period.

We need to correct two small errors in this account; the reservoir was at Summer *House* Hill, and the water drove *two* Pelton wheels.

The new generating machinery

Basically, the new machinery was planned (a) to double the electrical generating capacity, and (b) to work with pumped storage. To achieve these ends, an additional alternator, of 75kW, was installed, and four new turbines provided, so that the arrangement became as shown in Fig. 9. Here we have:

(1) In the centre, the original two Mordey alternators with the original reaction turbine centrally on the shaft between them, as shown in Fig. 8, and in addition a high-pressure jet wheel (HPJW), or Pelton wheel, fitted in place of the large pulley seen to the right of the turbine in Fig. 8. In times of adequate water flow in the river, electricity would be generated by the power of the reaction turbine; at other times, water from the high-level reservoir would be used and power developed in the jet wheel, no doubt usually as an addition to, rather than as a substitution for the reaction turbine.

(2) At the right, the new alternator, made by the Electrical Construction Co., with a HPJW on the same shaft, and a low-pressure jet wheel connected by belting. This arrangement was used in the same way as that in the centre.

(3) At the left, a low-pressure jet wheel to use the river flow to drive the pump on the far left, to pump water up to the high-level reservoir at times of low electricity demand. This wheel also drove an ice-making machine and the workshop tools.

It is interesting that the ECC and Mordey alternators ran at different speeds, 480 and 640 rpm respectively. This necessitated two different HPJW designs, since the two HPJWs were directly coupled to their alternators. That on the ECC alternator was 36in diameter, with 24 buckets each 2.5in×1.5in, with two nozzles, each with separate control valves. That on the Mordey alternators was 30in diameter, with 30 buckets also 2.5in×1.5in.

The low-pressure jet wheels were also different, because of their different functions. That driving the pump was a small compound wheel of only 8hp. That driving the ECC alternator was a double-wheel, 48in diameter, with two sets of 24 buckets, each 6in×3in, and with seven nozzles altogether.

A photograph of the station building at this time is shown in Plate 7.

Street lighting, charges, and method of operation

By 1899 the public lighting comprised fifty-nine incandescent lamps of 32cp and one Brush arc lamp of about 2,000cp on the Rhenish Tower at the end of the pier at Lynmouth. Iron poles were used in the main roads, and wooden ones elsewhere. Public lighting, as has been mentioned, was provided under contract to the Local Board, the rate in 1899 being £3 per incandescent lamp per year.

For private consumers, a contract basis was also used, this being at the rate of £1 per year for each 16cp lamp installed. Some consumers, however, were provided with meters, and they were charged *8d.* per unit in summer and *5d.* in winter for the first hour; all subsequent hours in the same day were charged at $4\frac{1}{2}d.$ per unit summer and winter.

The supply was commenced each day at thirty minutes before sunset and closed down at midnight. In December and January supply was given additionally between 6.30 am and 9.00 am.

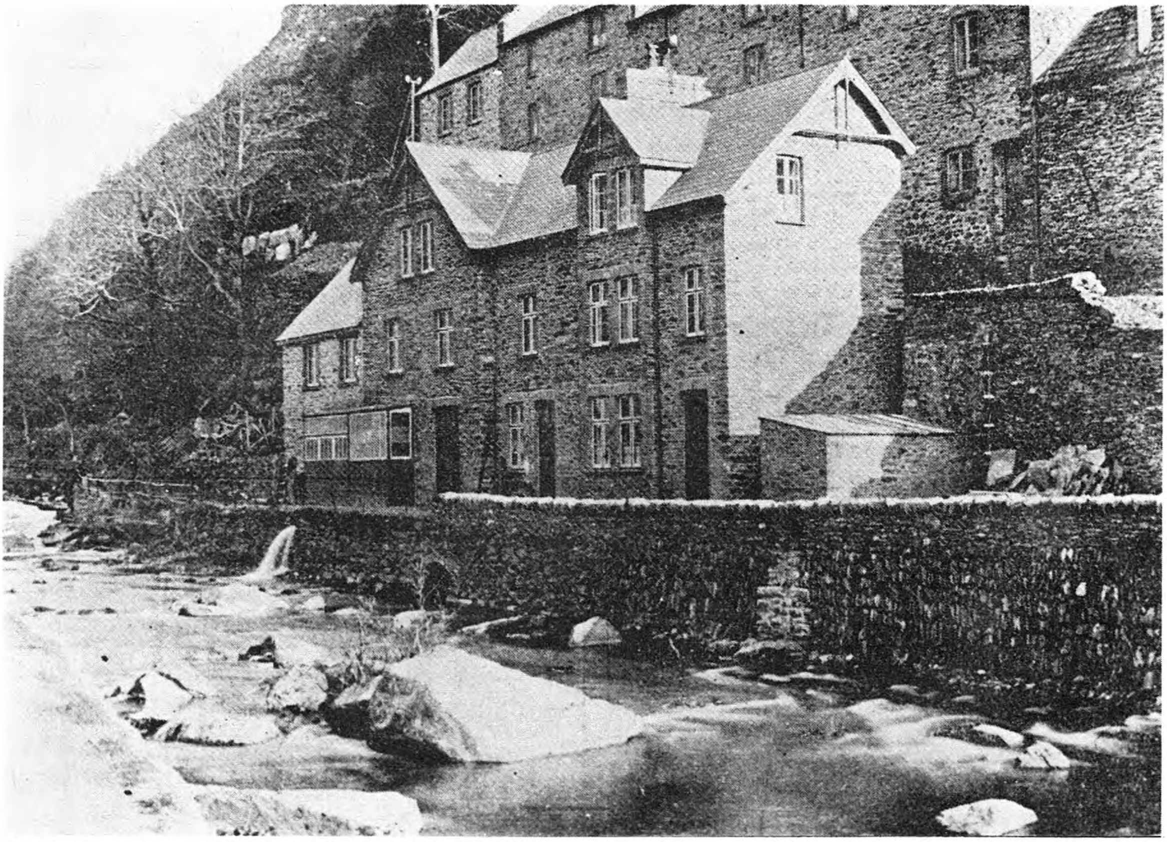


Plate 7 Photograph of Lynmouth generating station in 1899 (source as Fig. 9)

There was no day-load, so that all day-time water flow was available in principle for storage.

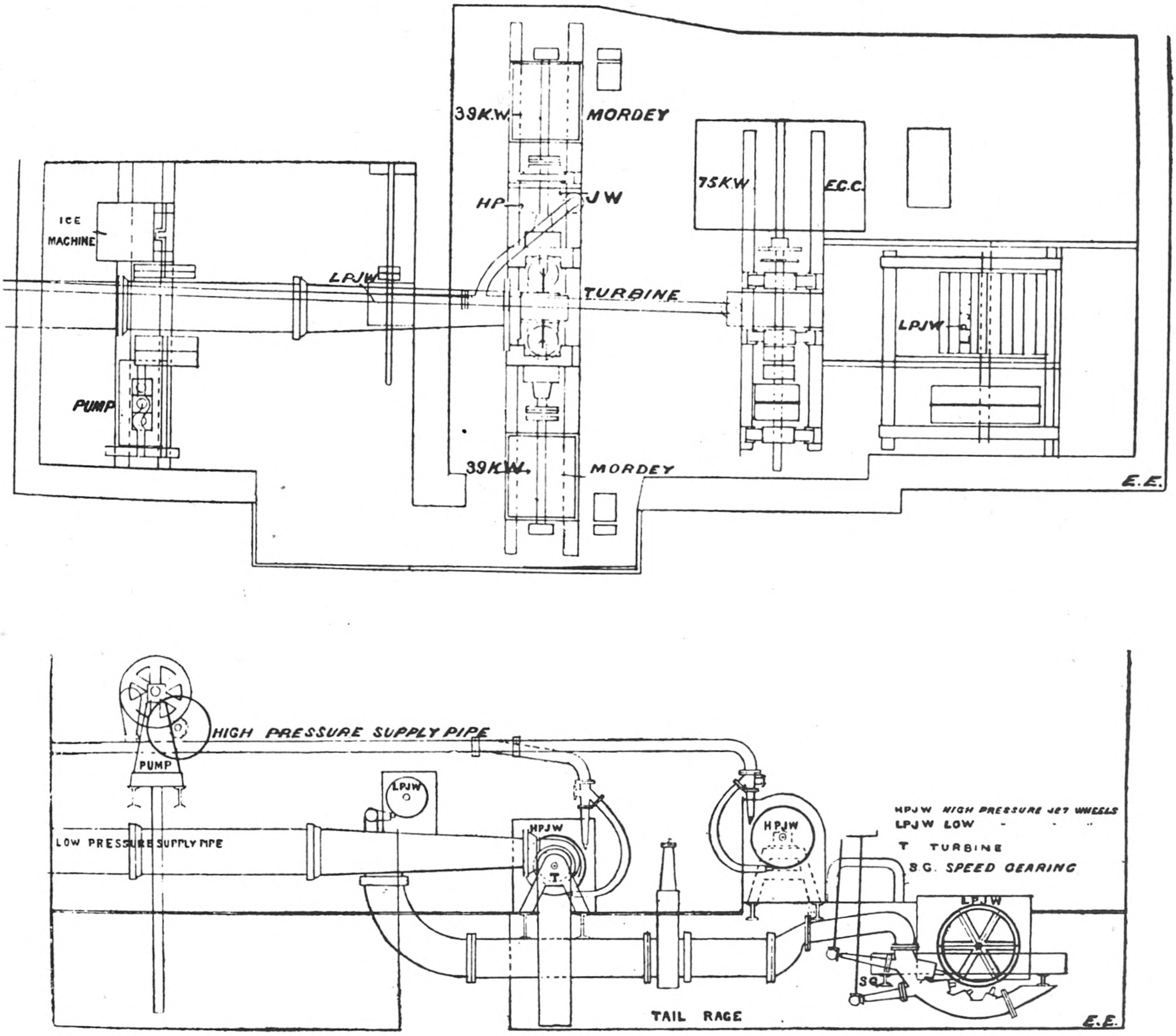
Difficulties with water supply

Up to July 1889, when the original system was planned, it was confidently believed, on the basis of local experience, that the minimum summer water flow would be sufficient to provide at least 200hp. However, it seemed the flow thereafter diminished every summer until by August 1898 only 20hp was available. The pumped-storage system considerably alleviated the difficulty, but did not entirely remove it, largely because of mechanical deficiencies in the pumping machinery. These were rectified in 1898, but at times in that year there was insufficient water to pump the reservoir full, and a restriction had to be put on the number of lamps customers could use, and for two weeks the voltage had to be dropped by five per cent. Hence a reluctant decision to install a steam engine was announced.

Whether a steam engine was actually installed is not at present known for certain. A brief historical account published in 1952[50] suggests that there never was a steam engine, but that 'more efficient turbines installed in 1904 and 1911 coped with the demand at Lynton and Lynmouth until 1921, when they were supplemented by the first two of a series of oil engines'. However, Garcke's Manual for 1903 and subsequent years shows a locomotive-type boiler and a vertical 30hp steam engine 'for possible emergency'. By 1923 Garcke shows two Parsons oil engines totalling 100hp in place of the steam engine. However, Garcke's information is not infallible, for he shows in years from 1910 to 1923 only two turbines (these being Escher-Wyss inward-flow turbines) whereas Mr. T. Brookhouse, who was engineer and later manager at the station from 1934 to 1948 is quite definite that the two high-pressure Pelton wheels were still in use, even in 1952. The Escher-Wyss turbines appear to have been installed in the early years of the century.

In later years, demand increased—it was nearly quadrupled between 1903 and 1920—and by the end of its life the station supplied a peak load of

Fig. 9 Plan and elevation of the Lynmouth generating station in 1899 (from *Electrical Engineer*, 23, 1899)



about 440kW (or more accurately, kVA). The Parsons engines were supplemented by a 100hp 3-cylinder Ruston-Hornsby engine (installed new about 1928), a 160hp 4-cylinder Sulzer engine (second-hand, about 1933), a 90hp McLaren-Benz 4-cylinder engine (second-hand, about 1938), and a 165hp 5-cylinder Ruston-Hornsby engine (second-hand, about 1947); and a number of new and second-hand alternators were also added. All this plant was still functional in 1952. The division of load between the oil engines and water power in the later years has been set out clearly in a letter received from Mr. Brookhouse, and we cannot do better than quote from it:

With regard to loads, these were very seasonal in character and peaked very badly at an early Easter and at a cold and wet late August/September period. In a similar manner, the split of load between engines and water plant was affected by very low river levels in the summer and partial choking of the intake screen with leaves during the autumn/early winter months.

The low pressure turbines were fed direct from the river with no storage of any description. The pumped storage plant had a useful sized reservoir but, except in emergencies, we could only use as much water over one peak load period as could be pumped back again during the period midnight to 6 a.m. A further point was that in my opinion the low pressure pipeline was only adequate to supply the original 150 h.p. 'Little Giant' turbine and that the two Escher Wyss machines were put in for alternate and not parallel running.

When both turbines were run the pressure loss in the pipeline prohibited the development of full rated power output.

Bearing in mind the above limitations the following loads and division of load were possible:

	kVA
(1) 1951/52, max peak load with good clean winter river	440
(2) *Continuous* output obtainable from low pressure turbines *only*, i.e. ignoring short-term capacity of impulse turbines	110
(3) 1951/2, max summer peak load with minimum river flow	330
(4) *Continuous* output obtainable from low pressure turbines *only*	55
For comparison	
(5) 1934/5 conditions as (1)	110 approx
(6) ditto conditions as (2) i.e. little use of engines during winter months except during excessive leaf troubles or periods of drought.	110 ,,
(7) 1934/5 max. peak at Easter	220 ,,
(8) ditto max. peak Aug./Sept.	170 ,,

The floods of August 1952

At the time of these floods, the South Western Electricity Board, which had by then become responsible for the system, was in process of changing over the district to a supply on the standard frequency of 50Hz, and a 33kV transmission line, operating for the time being at 11kV, had been put in to connect the area to the grid. Parts of Lynton were already using the new supply. So presumably the days of the hydro-electric system were numbered anyway, and the floods merely accelerated its demise.

When the floods struck Lynmouth, the engineer-in-charge (Mr. C. H. Postles), at considerable personal risk, kept the station running on the diesel engines until the flywheels were flooded, thus making further operation impossible. There was then a complete failure of electricity supply, which doubtless added considerably to the difficulties of the rescue operations. There was great loss of life as well as destruction.

Electricity staff were drafted in from other places to connect up emergency supplies of electricity, using the new line already partly in use. Since the frequency was different, there was a great deal of conversion work to be done. Day and night work at high pressure succeeded in a complete restoration of power within a few days.

The hydro-electric station was not rebuilt.

The present day

There are very few remains of the system now to be seen. There is no sign at all of the station itself, and the iron pipe joining the leat to the station was taken up after the floods. The concrete walls of the leat are traceable over much of its length, some of the overflows remain, and the entrance sluice to the leat is recognizable. A stone hut, 12ft square, which contained an automatic leaf-straining mechanism, still stands where the leat joined the pipe. The storage reservoir on Summer House Hill is hardly detectable, but Dr. Ferrer has found some pieces of 6in iron pipe below the site.

Chagford, 1891

The hydro-electric supply at Chagford, in Devon, was provided from a woollen mill, the water-wheel of which was used to drive an alternator. However, in spite of this apparently informal basis of generation, it appears from the table of generating stations supplied by *The Electrician* in January 1902 that Chagford's electricity was provided under a Provisional Order obtained in 1891; if that is true, it had full statutory authority from the beginning. Yet it was a small system with an installed capacity of only 20kW.

In November 1890 it was announced[51]

> There is a possibility of the electric light being introduced into Chagford. Mr. G. H. Reed, millwright and machinist, has leased part of a woollen factory there, and last week gave a demonstration with incandescent lights fed by a Joel dynamo. Mr. Eaton, of London, subsequently addressed a meeting at which he expressed surprise that with gas at 6*s*. 8*d*. per 1000, the electric light had not been introduced before. Mr. McSweeney, electrical engineer, also gave a lecture on electricity. A canvass of the town is said to have resulted favourably for electric lighting.

A fortnight later the registration of the Chagford & Devon Electric Light Co. Ltd. was announced.[52] Eaton and Reed had signed an agreement on 12 November 1890, and the company was registered on 18 November.[53] It had a registered office in London, and a capital of £2,000 in shares of £1.

Public lighting commenced on 1 September 1891 and presumably there were private consumers also. By 1900 there were the equivalent of 600 8cp lamps connected, with 16 lamps for street-lighting.[54]

The water power came from the River Teign by a leat, as shown in the map of Fig. 10. The generating plant was at grid ref SX 694878. The water-wheel was of undershot type, 14ft diameter and 14ft wide, and by means of belts drove two Siemens alternators with Crompton exciters. The voltage generated was 2000 at a frequency of 99 Hz. By means of 'Hedgehog' transformers the supply was changed down to 100V at the consumers' premises. By 1900 the distribution was by lead-covered, paper-insulated cable. The charges were then £1

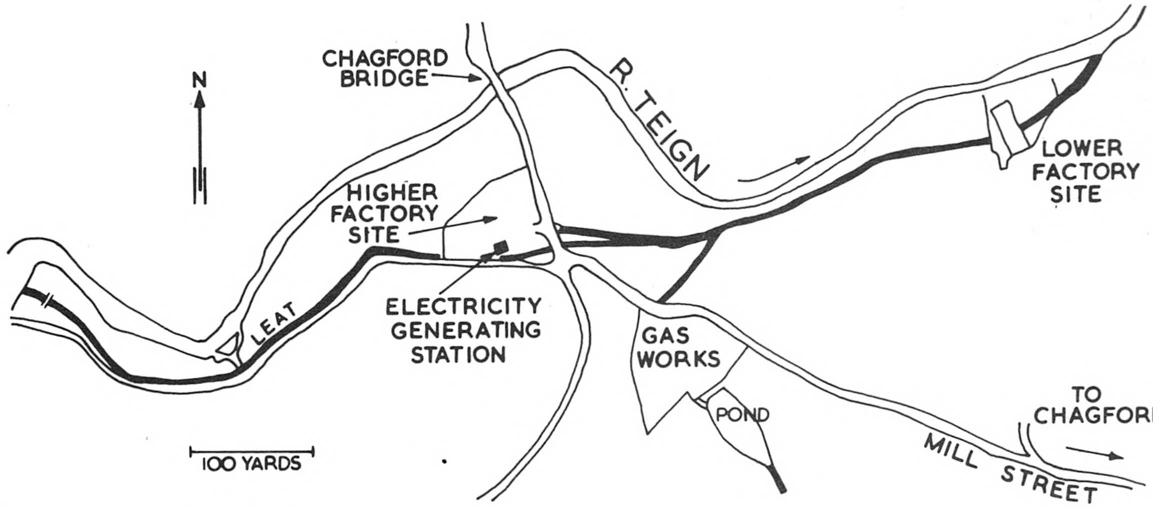


Fig. 10 Map of the leat and generating station at Chagford

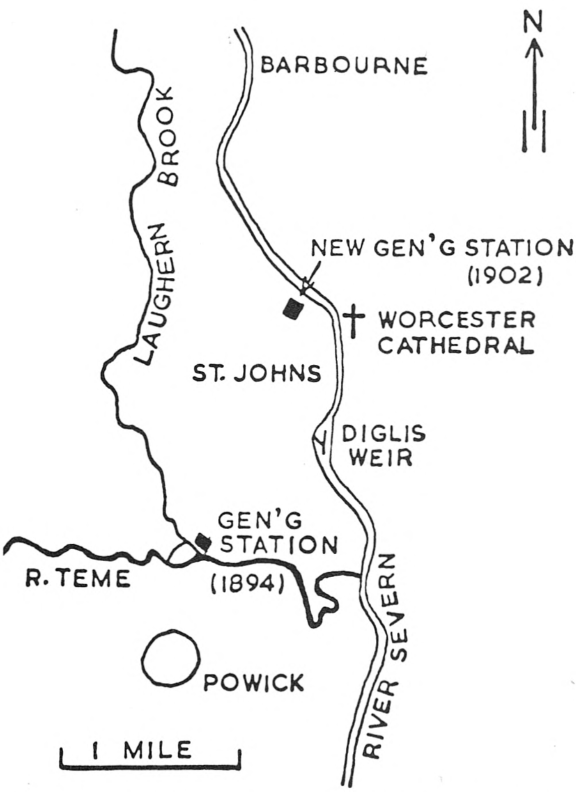


Fig. 11 Map of the Worcester area, showing principal locations

per annum per 16 candle-power, and were not based on metered units.[55] This charge was maintained for public lighting for about thirty years, but private consumers eventually had meters and were charged 6*d*. per unit in 1912.

G. H. Reed continued with the company as chief engineer, manager and secretary for a long time, probably for over twenty-five years.

The company expanded financially, having by 1922 expended over £7,500 on plant, although there were still only twenty-two public lamps and eighty consumers.[56] The expenditure on plant included the purchase of a gas engine made by the National Gas Engine Co., a suction gas plant, and a storage battery. Garcke's Manual shows the high-tension ac system and the water wheel as still in use in the 1920s, but Hellier[57] states that the system had become 200 volt dc in 1911 and that a 30hp turbine replaced the water wheel in 1914 and gave over fifty years' service; indeed, it may still be in use. The old mill buildings no longer stand, and the generating station is housed in a small building shown in the map. The company became part of the West Devon Electricity Supply Co. in 1930 and the station is now still in operation, with an installed capacity of 26kW, 3-phase ac, under the Central Electricity Generating Board and connected to the national electricity grid system.[58]

The early history of the mills, part of which Reed converted for the electricity generating station, is given by Helen Harris.[59]

Worcester, 1894

The city of Worcester was the first municipality in Britain to build, and operate on a long-term basis, its own hydro-electric power station. This was, moreover, with a water-generated power of up to about 400kW, by far the largest hydro-electric power station built in Britain in the nineteenth century for public supply. Indeed, for two years after its opening in 1894 it was the largest hydro-electric station of any kind in Britain, but was then somewhat overshadowed in size by the much larger plant of the British Aluminium Co. at Foyers in Scotland.

The Worcester generating station was at Powick, grid reference SO 835 525, two miles to the south-west of the city centre, on the River Teme not far above its junction with the River Severn. It used a head of about 10ft on the site where three old mills had stood. A map of the district showing the various river channels is given in Figures 11 and 12. There is a long history of water mills at Powick, both on the Teme and on the Laugherne Brook which flows into it here. There were two at the time of the Domesday Survey. In the thirteenth century the water of the Laugherne Brook had been diverted into the Teme above the present mill sites instead of below, so that when the hydro-electric station was built it was able to use the water of the brook as well as of the river. At the time the power station was being planned, there were three mills there, one (the easternmost) a corn-mill with two water wheels; one in the middle, also with two wheels, used for well over a century for grinding the raw materials for the Worcester china and porcelain works; and the third on the west, with three wheels, known as 'The Forge Mill'—this was probably out of use before 1890. The electricity generating station used the easternmost site, and the middle mill was not interfered with, although the Worcester corporation had to negotiate the terms of co-existence with the porcelain company.

This section traces the story of the generating station at Powick from the first stirrings in 1889 of effective interest in electric lighting in Worcester to the end of its reign as sole producer of electricity in Worcester with the opening of a new all-steam power station at Hylton Road in late 1902. (As far back as October 1882 the corporation had 'resolved to supply its own electricity', and in August 1883 *The Electrician* recommended it to use the water of the River Severn; but nothing came of this.) The

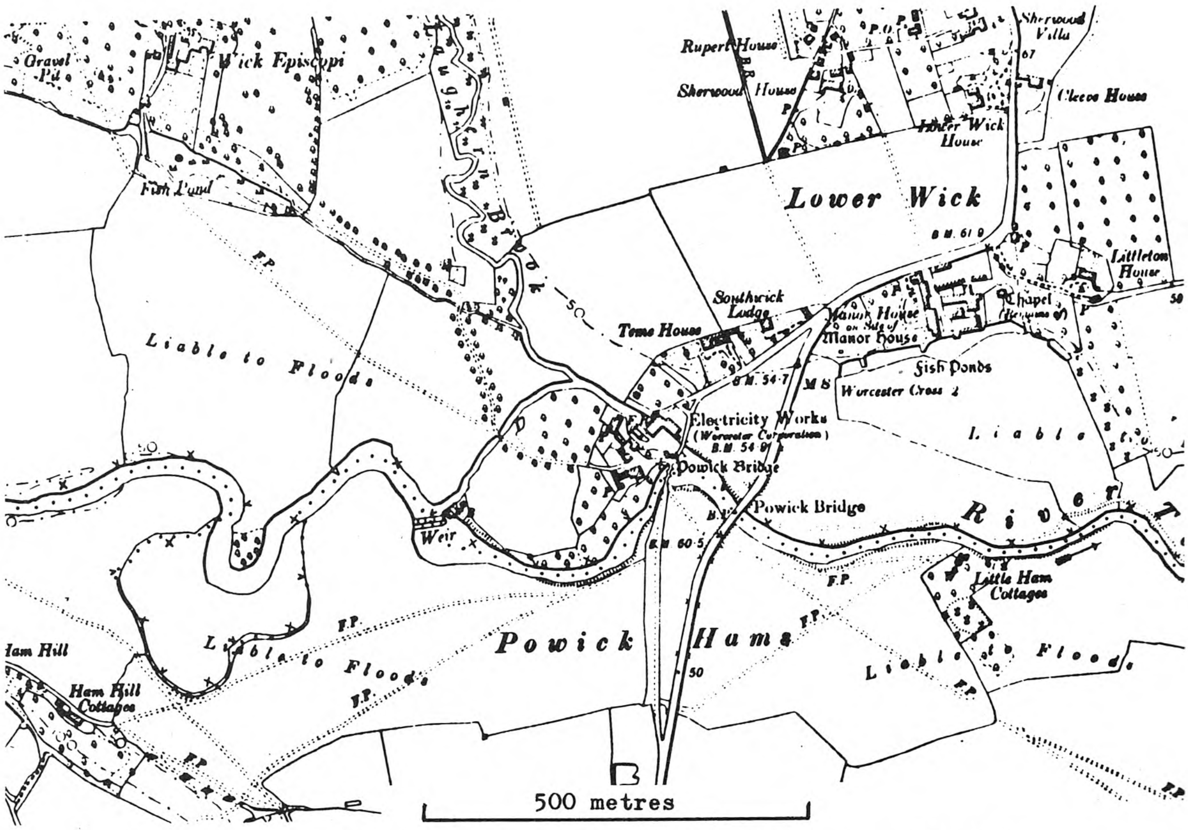


Fig. 12 Detail from 6-inch OS map of 1902 showing hydro-electric generating station ('Electricity Works') at Powick

information has in the main been obtained from the contemporary electrical journals. Over 170 separate reports in *The Electrician* have been used, together with some important ones in *The Electrical Engineer*. Individual references to these reports are not given in view of their large number. The annual reports and accounts of the City Electrical Engineer have also been used, thanks to the loan of the complete set for 1895-1925 by Mr. W. E. Price of the Midlands Electricity Board. The minute books of the council and the various committees of the city of Worcester have also been used where appropriate.

It will become apparent that

(a) the electricity generating system was not adequately planned in spite of 5½ years of discussion, the effective utilization of the water power being much lower than it should have been;

(b) nevertheless, the use of water power showed a large economy over comparable steam-driven generating stations.

The building still exists, and some photographs of it are shown in Plates 8-10.

The beginning

After the amended Electricity Act of 1888, many companies obtained Orders for the provision of electric-lighting generating stations and distribution systems. Several municipalities were stimulated by the rapid technical advances and possibilities of profit to obtain Orders to set up their own electricity supply systems.

In Worcester, the committee which found itself in the position of responsibility for electrical matters was the Watch Committee, which in 1890 became the 'Watch and Lighting Committee'. At the beginning of April 1889 it considered an approach from the Anglo-American Brush Electric Light Corporation offering to submit a scheme of electric light in the city. It referred this to the Lighting Sub-Committee, which henceforth had to deal with electricity as well as gas. By September, the Town Clerk informed the Watch Committee that several companies had given notice to apply for Provisional Orders authorizing them to supply electricity to the city, but the Watch Committee decided not to recommend the corporation to do anything about the matter. Nevertheless the city council did immediately decide to take action and applied to the Board of Trade for a Provisional Order to authorize the corporation itself to supply electricity in Worcester. At that time the estimate of capital expenditure was £15,000. The Order was confirmed and notified to the council in August 1890. The Town Clerk suggested to the Watch and Lighting Committee that some electric light companies should be approached as to the terms upon which they would carry out the work for the corporation. However, the committee recommended the appointment of Mr. G. E. B. Pritchett of Oxford Street, London, to report on the best way of carrying out the order, the probable initial cost of providing electric lighting works in Worcester, and the subsequent expense of maintenance. The council agreed.

Pritchett reported in November 1890, agreeing that the corporation should undertake the supply, but suggesting that it should first investigate the likely demand for light. He also suggested the use of water power and proposed the Diglis weir on the River Severn for the site of the station.

Nothing was done about the matter until May 1891, when the City High Sheriff, Mr. J. Millington, offered personally to take on the powers under the Order and develop the supply privately. This stimulated the council to action, for they declined the offer and instead appointed (through the Watch Committee) Mr. O. R. Swete, 'electrical engineer', to ascertain the probable demand for electric light. This he did, and reported to the Watch Committee in October 1891 that a satisfactory demand for electric light and power existed; he had received 189 requests aggregating a load equivalent to 13,660 incandescent lamps of 10cp.[60] He had but little doubt that if the inquiry were extended a load equivalent to 16,000 lamps would be obtained. After consideration by the sub-committee, the committee asked the council in November to authorize it to advertise for tenders for the construction of electric lighting works with a capacity of 12,000 10cp lamps. The council agreed.

By March 1892 fifteen tenders had been received, and Mr. W. H. Preece, FRS, was engaged to advise the council. Preece was a very distinguished electrical engineer, at that time Engineer-in-Chief of the Post Office and best known for his work in telegraphy. He was, however, allowed (or at any rate, not forbidden)[61] by the Post Office to engage in private consulting practice, and as he had an extraordinarily wide grasp of electrical engineering, he was in much demand as a consultant on new electricity supply schemes. For example, he was already engaged on the complete technical direction of the design of the Bristol Electric Lighting works and its distribution system at this time. At Worcester his duties were lighter. He reported within a fortnight,

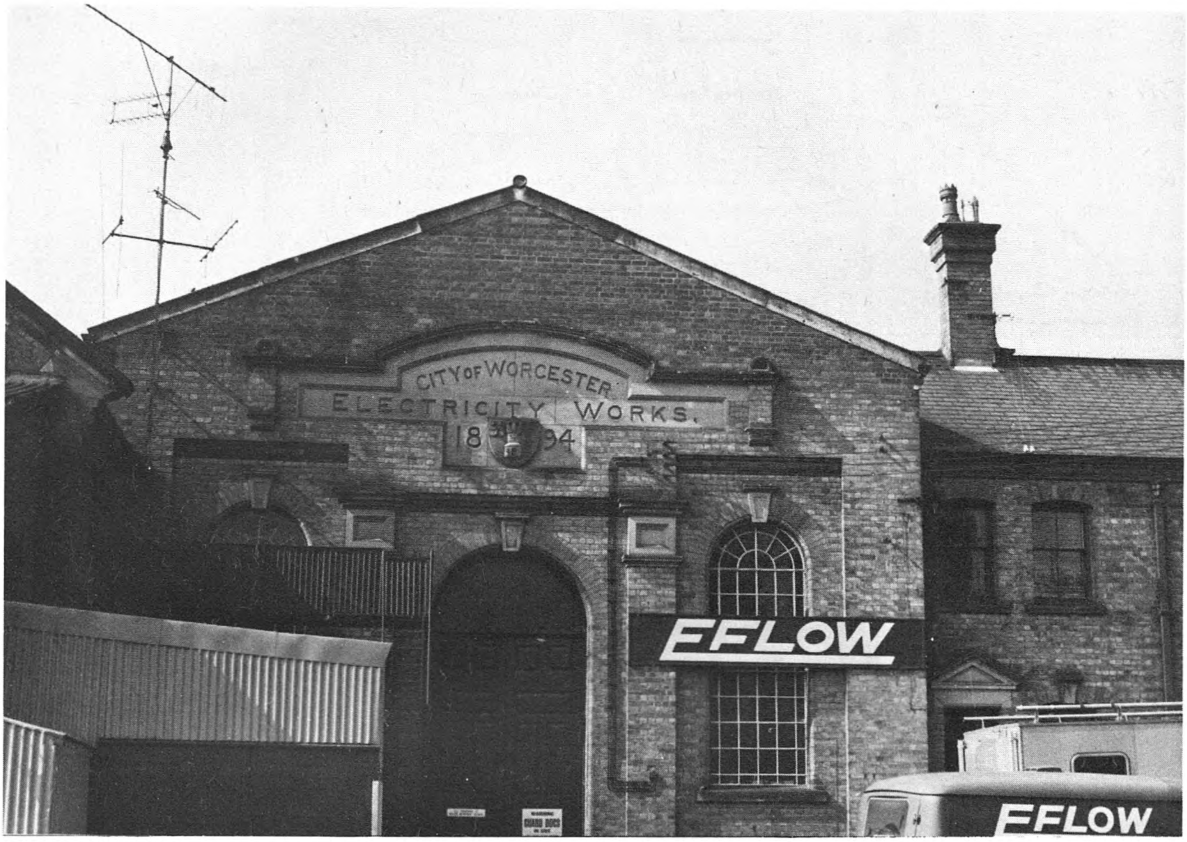


Plate 8 The old hydro-electric generating station at Powick, Worcester, in 1972 (Photo by D. G. Tucker)

and the Town Clerk presented the report to the Watch Committee:

Mr. Preece estimated the annual revenue to be derived from the proposed plant when it was fully taken up, if 6*d*. per Board of Trade unit be charged, at £10,800, and the total working expenses £5,500, showing a profit of £5,300. The estimated cost of building at the weir was £6,900, but the reduction in the cost of working expenses through the use of water power fully justified this. He estimated that they would require £40,000 for their undertaking.

The committee decided to recommend that the Brush Company's tender be accepted. This was for a combined steam and water power plant at £21,005. It was the lowest tender by a very small margin, but there were several tenders more than fifty per cent higher, and that of the Electrical Construction Co. was no less than £39,165. Buildings, street lighting, etc., would cost another £19,970.

Brush proposed an ac system, which was supported by the Watch Committee but opposed at first by the council who wanted a 'storage' system, i.e. dc with batteries. After a lot of argument, the council, in June 1892, accepted ac, but deferred acceptance of the Brush tender while the question of water power was further examined:

... it was decided, after considerable discussion, by 28 votes to 10, to accept the Brush Company's tender, subject to obtaining the sanction of the Local Government Board to the requisite loan, and subject to a report from the Watch Committee as to (1) whether provision should be made for steam power only, or steam and water power combined; (2) whether provision should be made for street lighting.

The Brush tender was revised to £15,980; or with street lighting £22,680.

By October 1892 it was clear that the Severn Conservators opposed the proposal to use the Diglis weir for electric power generation. However, an offer had been received, presumably from their owner Mr. Willis Bund, for the grant of a lease of the Powick Mills on the River Teme for 99 years at £160 per annum, or alternatively for the sale of the buildings and site for £5,000. The Brush Company had reported on the best way of utilizing the Powick site. So the Watch Committee decided to abandon the Diglis proposal and instructed the surveyor to report on the power likely to be available from the

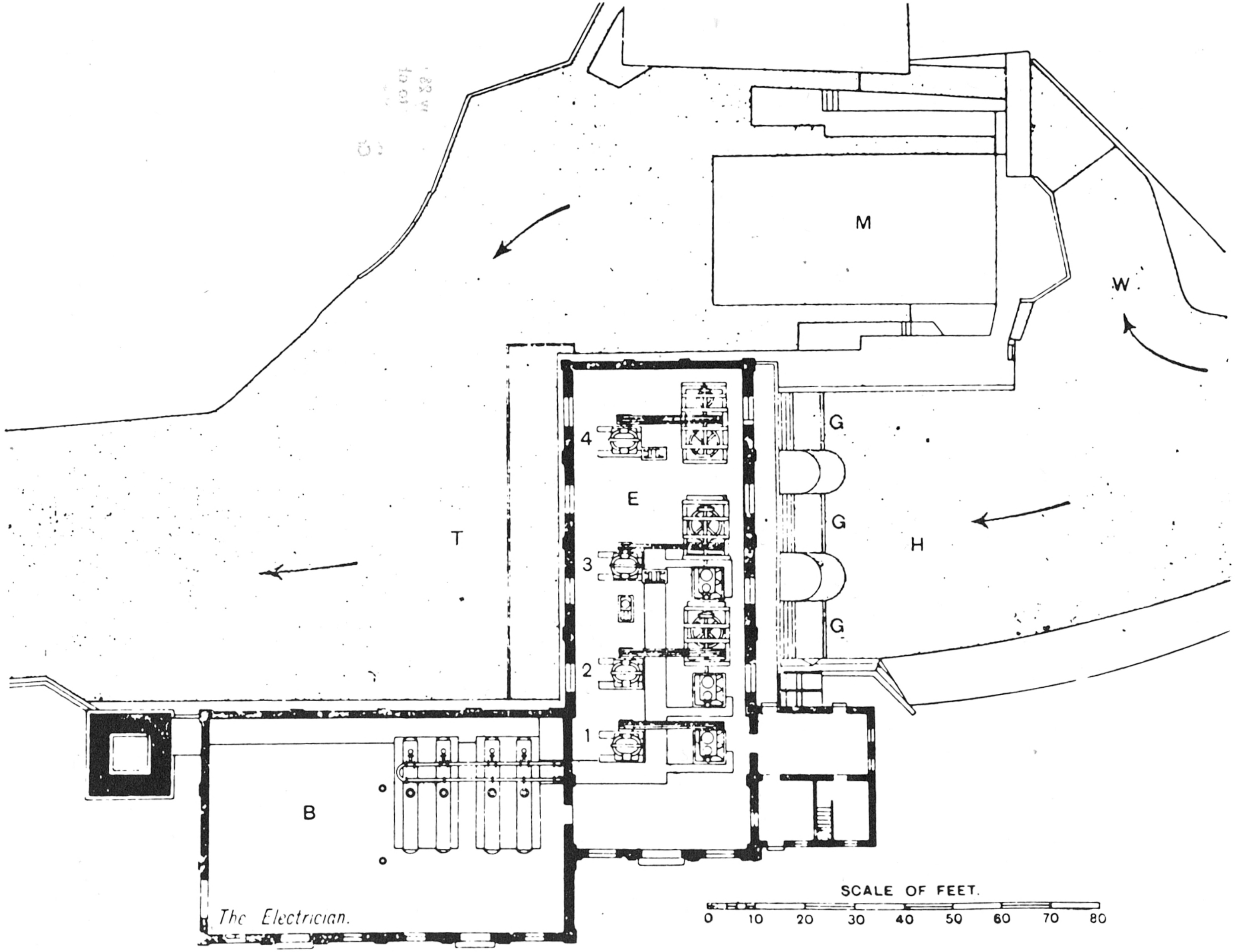


Fig. 13 Plan of the Powick site (from *The Electrician,* **33,** 5 Oct. 1894)

B boiler house
E turbine house
G grid-iron gratings to strain the water
H head-race
M old mill
T tail-race
W by-wash to mill M

Fig. 14 Façade of Powick generating station (from *The Electrical Engineer*, **14**, 12 Oct. 1894)

Teme and on the possibility of navigating the Teme up to the mills.

By early December 1892 the Watch Committee had recommended, and the council after much discussion had agreed, that Powick Mills should be bought for £5,000, and that the revised Brush tender of a total of £23,209 should be accepted. By utilizing the water power of the Teme, a saving of £1,416 per annum was expected. At the Local Government inquiry in April 1893 regarding Worcester's application for a loan, Preece's representative, Mr. W. Geipel of the Brush Company, stated that the maximum water power available was estimated at 1500hp, and turbines for upwards of 600hp were to be installed at once, current being likely to be available early in 1894. The loan was sanctioned in June. Nine thousand pounds was approved by the council for the cost of the building. Yet the matter was still not really settled, for in August 1893 there was an obviously difficult discussion in council in which one group pressed for the Powick proposal to be abandoned in favour of a steam-only generating station in the city itself at a cost not exceeding £20,000. Voting was 10 for this proposal and 22 for Powick. Thus was the matter finally settled.

A tender of Thomas Rowbotham of Coventry Road, Birmingham, for constructing the buildings for £14,797 was accepted, and Preece was appointed consulting engineer for the works, with Mr. Leonard Wigan as clerk of the works. Preece's commission was to be 2½ per cent on the amount of the Brush contract, i.e. about £600—not bad seeing that he was also consultant to other undertakings and had a full-time job with the Post Office! The Highways Committee of the county council concluded an agreement with the city in respect of the laying of mains from Powick to the city.

One interesting side issue at this time was the question of the lighting of the workhouse. The Board of Guardians had numerous discussions as to whether they should adopt the electric light. At one stage they were thinking of having their own electric light plant. Yet in September 1893 they decided by a small majority to adopt gas lighting in the workhouse. Of course, in the end they had electric light.

Another matter of interest was that, in order to make some use of the available flow of water by day (for, of course, at first it was expected that the normal load would be almost exclusively lighting, drawing power only at night), the pumping at the municipal waterworks was to be done by electric motors. The council voted £2,089 for this purpose. This pumping load, during the first year or two of operation, absorbed no less than 41.9 per cent of the total power sold, and being contracted at a price per unit below the cost of generation, led to some difficulties.

Construction and opening

A diagram of the site as developed is shown in Fig. 13. The façade of the building is shown in Fig. 14, and a vertical section in Fig. 15. Work started in the late autumn of 1893, but there were heavy rains and a 'landslip' (probably the collapse of a temporary dam) caused a setback, causing all the work at Powick to be submerged. Nevertheless very good progress was made, and by August 1894 the opening date of 11 October 1894 was fixed—and it was adhered to! The Mayor, Mr. G. R. Williamson, performed the opening ceremony and commended all concerned with the work. He said that every ratepayer was a shareholder in this profitable business on the co-operative principle, selling a commodity 'which was a distinct advantage to the health of those who used it in preference to gas for illuminating purposes and also would be a cheaper substitute'.

Preece spoke on the great advantages of having water power; the heaviest load was between 4 and 9 p.m., yet although for the remaining nineteen hours of the day the machinery was virtually idle, it must be kept going. In other places the cost of electric lighting was increased by the waste of fuel during the idle hours; here the waters of the Teme kept the light going at a minimum of expense. There were other speakers, then lunch in the Council Chamber, and in the evening a banquet for 300 in the Guildhall.

In the afternoon an electrical exhibition in the Public Hall was opened by the Mayoress, with a large reception. This had been organized by the Watch Committee to demonstrate electric light and appliances in order to encourage business.

In the evening the street lighting was switched on, and was successful. With a few private consumers the initial load was equivalent to nearly 5,000 8cp lamps (probably over 200kW). It was supplied entirely by water power.

Technical description

No artificial millpond was built, so that the only water storage was that in the headrace itself. This means that it was not even possible to store enough water by day to augment the supply for the night load. Hence the need for a day load, provided by pumping motors at the waterworks as previously

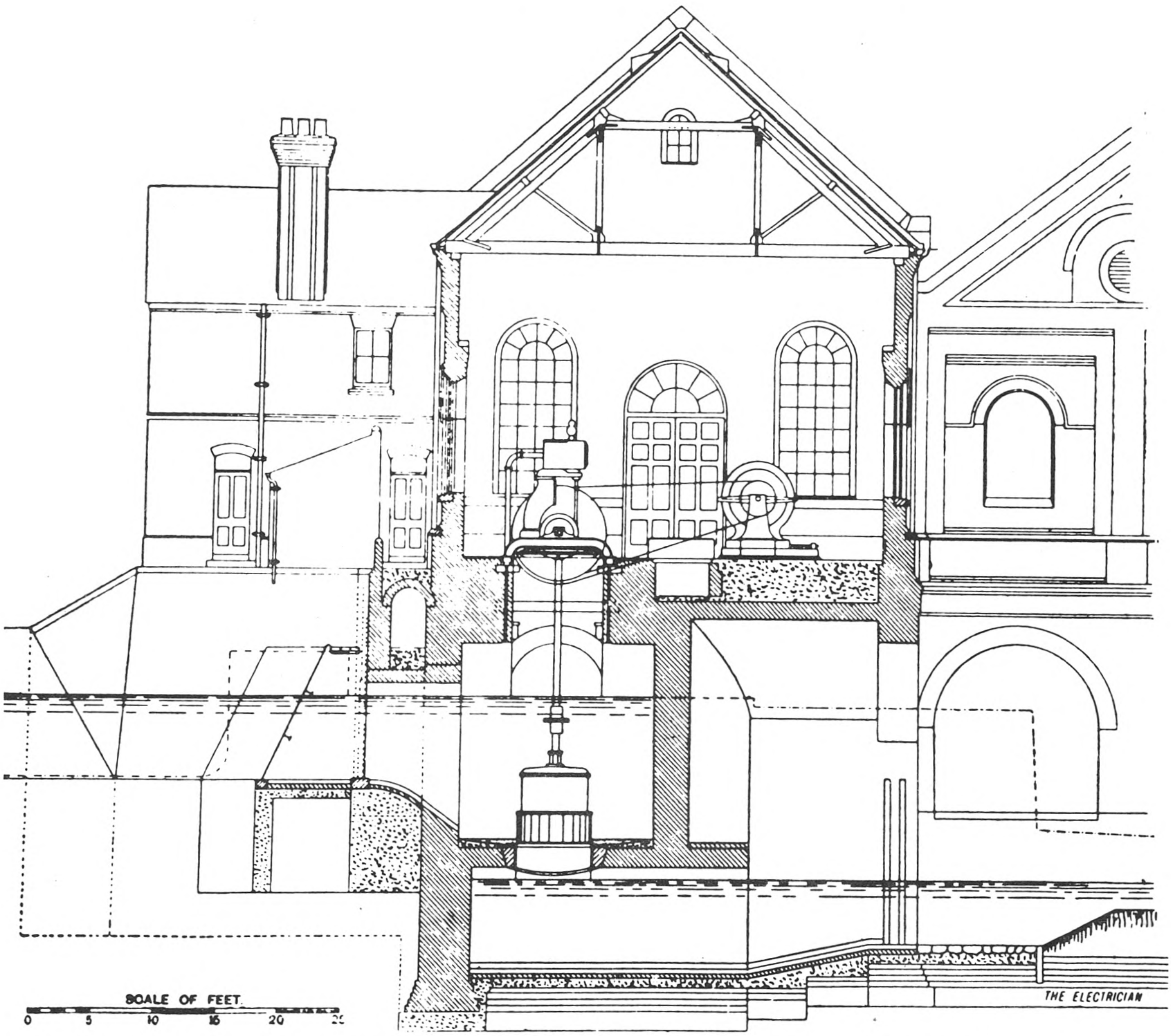


Fig. 15 Vertical section through Powick generating station showing turbine pit (from *The Electrician*, 33, 5 Oct. 1894)

mentioned; and the need for steam power to assist in the night load. Moreover, at times of drought there was no water to drive the turbines, and at times of flood the tailrace was flooded and there was no head of water. Thus, of the four 125kW alternators, marked 1-4 in Fig. 13, nos. 2 and 3 were arranged to be driven by 160hp water turbines or steam engines or both together, while no. 1 was coupled only to a steam engine and no. 4 only to water turbines. So that a very small load could be efficiently supplied, no. 4 alternator could be coupled to a 60hp turbine, or to a 100hp turbine, or to both.

The four boilers were of 124hp Babcock & Wilcox water-tube type, working pressure 120lb/in^2, capable of evaporating 4,000lb of water per hour; firing was by hand.

The three main steam engines were of Brush compound vertical type, developing 286hp. Cylinders were 15 and 25in by 16in stroke; speed was 167rpm. Condensers were not fitted initially but were added in 1895.

The turbines were of the mixed-flow type; the water passed from the wheel pit through guide vanes radially in to the upper part of the turbine wheel, the blades of which absorbed some of the power and directed the water axially through another set of blades in the lower part of the wheel. The water then left the turbine through the draught tube, the lower end of which was immersed in the tailrace; this system enabled the full head of water to be effective however high the tail water might stand. Water flow through the turbines was controlled by a cylinder gate around the turbine wheel.

The four alternators were of the Mordey-Victoria type (NB Mr. Mordey was present at the opening ceremony), rope-driven at 430rpm, generating up to 58A at 2200V. They had stationary armatures and rotating field magnets, excited by two Brush-Victoria dynamos each of 5.83kW, together with one of 6.5kW. The first two exciters were driven from the shafts of two of the alternators, and the third by a separate small steam engine, which could also drive the other two if required. This flexible arrangement meant that all requirements of variation between day and night loads could be met.

Switchboards were of Raworth's interlocked type. The high-voltage feeders from Powick to the distributing sub-station at All Hallows were of the Brooks oil-insulated type. There were three heavy wrought-iron tubes, with the minimum thickness of 0.25in and internal diameter 2in. Each feeder was made up of two 19/14 conductors and two pilot wires laid together into one cable (see Plate 11). There was an oil pressure tower midway along the route to take up variations in volume due to variations in temperature. The feeders were shown to be quite safe at the working voltage, as they did not flash over below 5000V. They were manufactured by Johnson & Phillips, who also laid them. This kind of high-voltage cable had been introduced in 1887 by David Brooks in the United States. The conductors, which were lapped with jute yarn, covered with hessian tape, and braided overall, were drawn into the iron tubes *in situ* through impregnating tanks.[62] Although the Worcester cables were satisfactory and remained in service for over thirty years, the system did not become popular. Nevertheless it can be regarded as laying the foundation for the modern oil-insulated high-voltage cable.

Early operating experience

The analysis of the operating costs for 1895 given in the City Electrical Engineer's report is extremely interesting. It was a dry summer, he said, and the water flow in the river was so low that steam had to be used to supply electricity for the waterworks motors, this accounting for about 400 tons of coal. Overall, a total output of 246,912kWh was supplied, but no less than 41.9 per cent of this was for the waterworks motors. Although the commercial load of 143,268kWh was charged at an average of 3.99*d.* per kWh, only 1*d.* per kWh was obtained from the Water & Sewerage Committee for the pumping load. This meant the total income from the pumping load was only £431 17*s.*, a very small contribution to the total operating cost of £3,057, to which had to be added £893 for interest and £952 towards the sinking fund. Since the total earnings were £3,254, this left a net deficit of £1,549 on the year's working.

It is not surprising that in April 1896, the council decided to raise the charge to the Water & Sewerage Committee to 1½*d.* per kWh.

In 1896 the number of electric lamps supplied was increased from 14,605 to 21,958, but in spite of this and the increased charge to the waterworks, the net deficit for the year, £1,616, was greater than for 1895.

In April 1897, the council agreed to change the basis of charging for the lighting supply from the former flat rate of 5*d.* (figures in old pence) per unit (kWh) to 6*d.* per unit for the first hour in each day and 2½*d.* per unit afterwards. All discounts were abolished, but free lamps were to be given instead for prompt payment! It is believed that the rate for cooking, heating and motive power was 3*d.* per unit throughout the early years.

With expansion of business, extensions of mains and generating plant, revision of rates, etc., the annual deficit was reduced year by year after 1896 until a net profit was shown for the first time in 1899, in which year 551,437kWh were sold, the station capacity having been increased (using more steam power) to 900kW.

In spite of the difficulties with water supply, the electrical engineer reported in March 1897 that 'the adoption of water-power at the generating station had during the past year been justified, despite the dry season and the failure of the turbines to generate the power contracted for'. He seems to have had some justification for this statement. In 1895 the actual cost of generation and distribution at Worcester was only 2.97*d.* per unit. This was at the time a lower rate than applied in other places. For example, at Bristol (where coal was cheaper than at Worcester), the cost per unit was about 4.5*d.* This fell to 2.5*d.* by 1899, but by then Worcester had fallen to 2.0*d.*

Inadequacy of the water power and criticism of the scheme

It is clear from the early annual reports that the water power did not come up to expectations.

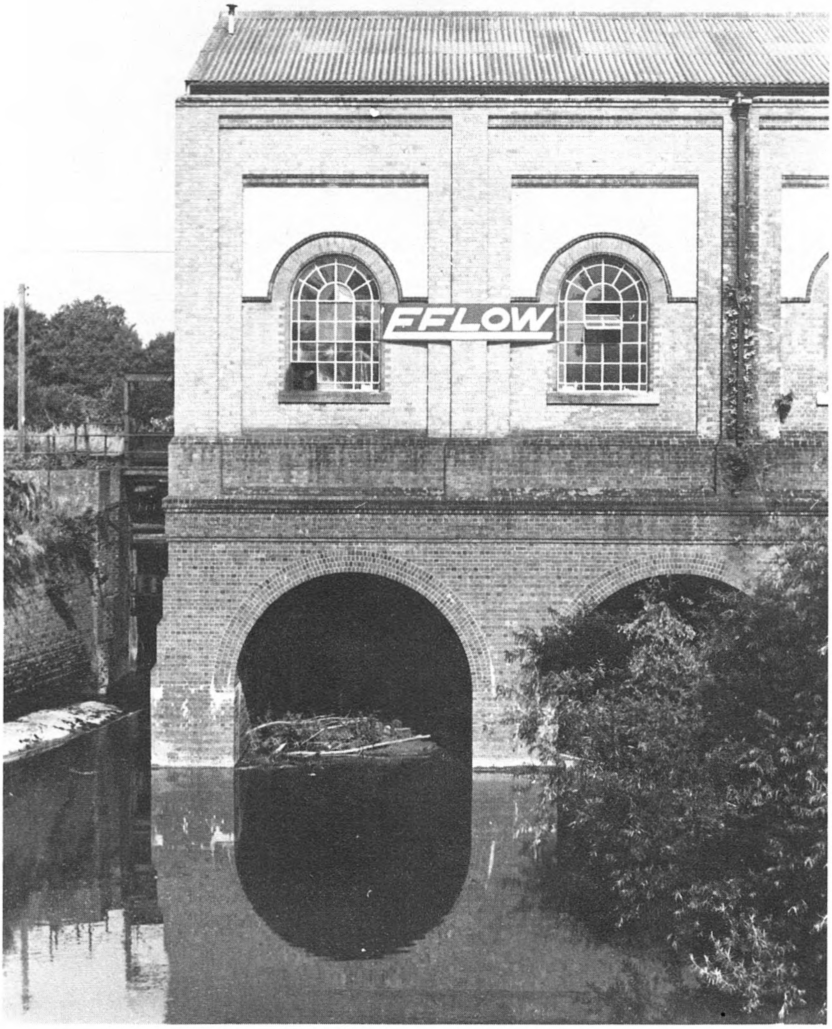


Plate 9 The tail-race at Powick, in 1972 (Photo by D. G. Tucker)

In 1892, Mr. S. G. Purchas (city engineer) reported that the flow in the Teme could be relied upon to yield 850,000 horse-power-hours in an average year. This is approximately an average power of 100hp. Allowing for losses in conversion to electricity and in distribution, this is about 60kW of electrical power.

In April 1893, Mr. Geipel of the Brush Company, as we have already noted, stated that it was estimated that the maximum water power available was 1500hp, and that it was on this basis that turbines 'for upwards of 600hp' were to be installed. So already there was a serious discrepancy. The use of 'maximum' water power as a basis for planning was clearly absurd.

At the meeting of the city council on 15 August 1893, the mayor said:

> Whatever doubts they might have had as to the wisdom of obtaining electric energy from water power had altogether been cast aside by the fact that in spite of the long and protracted drought there had been no day when less than 300 h.p. would have been available at Powick.

From the electrical engineer's report for 1895, it can be deduced, very roughly, that the normal river flow that year yielded little more than perhaps 15kW of electrical power, or say 25hp at the

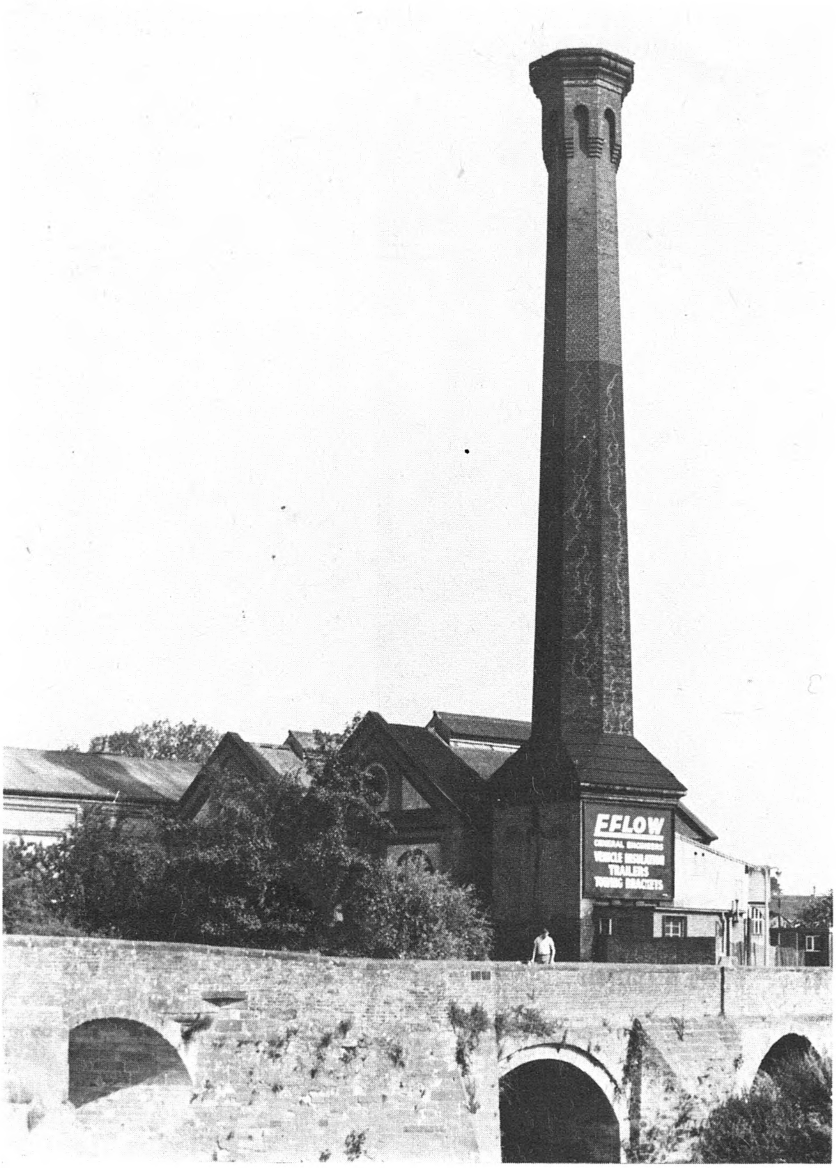


Plate 10 The Powick works from the south, in 1972 (Photo by D. G. Tucker)

turbines. It was ultimately found that in a good year about 250,000kWh could be generated.

It looks very much as though the engineers (especially the consultants) had not done their homework properly in this respect.

The electrical engineer's annual reports refer several times to a hydro-electrically unsuccessful year (e.g. 1895, 1896 or 1899) as being an abnormally dry one. For example, the engineer's report presented in March 1900 said that 'last year was the driest we have had since the station was started'. Instead of over fifty per cent of the power being generated by water, only 41.7 per cent was.

In the early part of the year when we expect a good deal of benefit from its use, a series of floods lasting much longer than usual occasioned us considerable loss. In January and February there were 28 days on which the water power was not used at all,, and during most of the remainder owing to reduced head it was of little use. . . . From July right up to the middle of November we had a drought of most unusual length . . .

The excuse of abnormal drought is quite unjustified by the available rainfall figures. Unfortunately only annual totals are available for Worcester itself and for Tenbury higher up the Teme valley, these being given in the annual volumes of *Symons's British Rainfall.* These figures, however, are quite sufficient to dispel the idea that 1895, 1896 and 1899 were abnormally dry. The rainfall in 1899 was over two inches above the average for the decade (1890-99) at both Worcester and Tenbury, that in 1895 was above the average at Worcester, and only that of 1896 was below the average at both places.

Monthly rainfall figures are available (in the *Meteorological Record* of the Royal Meteorological Society) for Cheltenham, which is only just over twenty miles from Worcester. When these are suitably tabulated, it is found that the annual totals at Cheltenham correlate reasonably well with the figures at Worcester and Tenbury, and it is possible, therefore, that the monthly rainfall pattern at Cheltenham is reasonably representative of that appropriate to Powick. From July to November 1899, inclusive, the rainfall at Cheltenham totalled 11.1 inches out of the annual total of 25.7 inches—hardly a drought! The January and February rainfall of that year was, however, abnormally high—6.4 inches for the two months, the highest figure for January and February in the whole decade. So while the flooding in January and February 1899 can be accepted as true, we have to remain very sceptical about the excuse of drought, and can only speculate as to why this excuse was so often given without justification.

The solution to the difficulties experienced, in spite of the fact that we have not been able to demonstrate the causes with any conviction, would probably have lain in water storage. A large storage reservoir could have contained flood water and allowed it to be used in times of drought. Often storage can act as an effective means of controlling floods, but this would not have applied very fully here, since the flooding at Powick would have been mainly caused by the flood-waters of the River Severn running back up the Teme. Whether this large storage reservoir would have been economic is another matter, now hard to determine. On the other hand, a small storage reservoir, large enough only to store the daytime flow and release it at night when the electricity load was large, would almost certainly have paid a handsome profit. In 1895 there were only two really dry months, and yet it was reported that 400 tons of coal were used merely to provide the power for the waterworks' pumps during the dry spells. Coal was about 7*s*. a ton. If we assume that daytime storage saved only £200 in coal costs per year, it would pay to provide the storage if the capital expenditure did not exceed say £2,000. For this it should have been possible to provide storage of perhaps 5,000,000cu ft, which at 6,660cu ft per kWh (unit) generated would provide for the generation of about 750 units. The average daily commercial consumption of electricity in 1895 was about 400 units, so this storage would have been sufficient in itself for two days' supply even if there was no flow in the river at all.

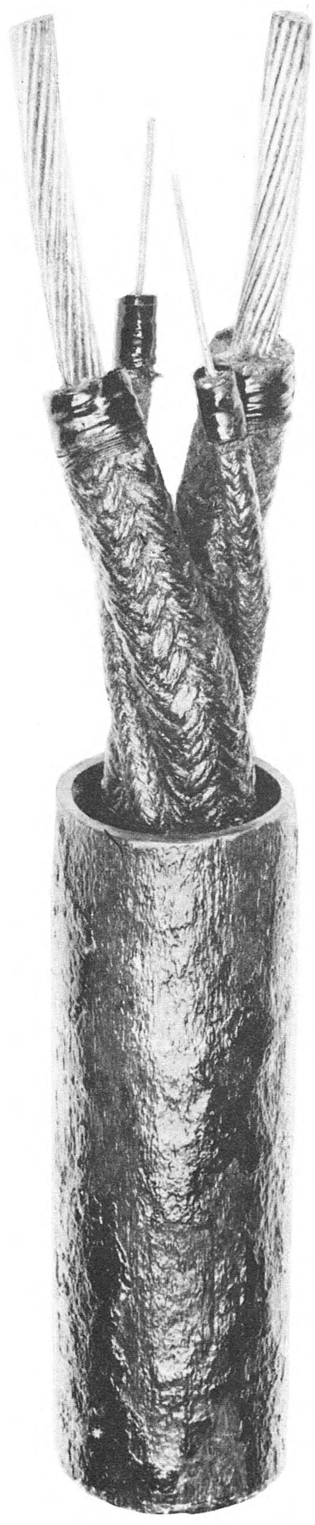
The figure of 6,660cu ft per kWh is derived from technical data given in the published description of the plant, assuming a head of 10ft and an overall efficiency of conversion from mechanical power at Powick to electricity in Worcester of 80 per cent. The cost of building a reservoir is a guess based on figures given for a much larger and probably more difficult reservoir by Henzell,[63] and is probably an upper limit for cost as it is ten times that obtained from some figures given by Fairburn[64] for the cost of constructing reservoirs in Ireland at a somewhat earlier period.

It is thus rather puzzling that the building of a reservoir was apparently never even contemplated. The authorities all seemed satisfied that the provision of a day-load was the solution to the problem—which it never was, since this load was never charged at anything like the cost of production—and the £2,000 which the council spent on motors for the waterworks would have paid for a reservoir anyway!

Staff and personalities

Mr. Thomas Caink, who had been assistant city engineer to Mr. Purchas, was city engineer during the construction of the Powick works. He apparently took it upon himself to authorize extras on the contract to the extent of about £5,000, and this, when it came to light, invoked severe criticism from the Electrical Committee (which had apparently been formed as a separate committee at the beginning of 1895) and from the council. In May 1895, the council decided to reduce his salary from £450 to £350 a year, 'in consequence of the appointment of an electrical engineer who will relieve Mr. Caink of certain duties in connection with the installation of the electric light in the city'. One can read between the lines here!

The post of electrical engineer had been advertised late in 1894, and there were thirty-six applications. At the beginning of January 1895 a short-list of three was prepared: Mr. E. T. Ruthven Murray of Aberdeen; Mr. S. J. Mahood, resident electrician for the Worcester works; and Mr. L. Wigan, clerk of works at Powick. When the appointment came up for discussion at the council, it was referred back to the Electrical Committee, 'it being



the opinion of the councillors that the duties of the office were to be undertaken by the City Surveyor [i.e. engineer]'. The result of this action was that Mr. G. H. Williamson, chairman of the committee, and all the other eight members of the committee, tendered their resignations. The council declined to accept the resignations, but agreed to appoint Mr. Murray, who was in charge when the Powick station was taken over from the contractors at the end of February 1895.

Some members of the council made further difficulties over the appointment of junior staff for Powick, but these were approved by a majority decision.

Murray's salary was £250 on appointment, and was increased, after a good deal of bother in the council who at first refused an increase, to £350 in December 1897. Murray resigned in October 1898, and the post was advertised at £350 per annum. Mr. C. J. Sutherland was appointed to it. He was very ill in 1899-1900 and was away from work for over fourteen months, but was back in harness by late 1900.

The city electrical engineer's lot could not have been an over-happy one. We read, for example, in *The Electrician* for 17 March 1899 that when the accounts for 1898 were presented to the council:

> Contrary to custom, the discussion was of a harmonious character, and, instead of indulging in personal recrimination, members took to congratulating one another [note: not congratulating the engineer!] on the pleasing prospect of a profit on this year's working.

The city and the electrification of the tramways

Like so many towns, Worcester had a horse-operated tramway system, owned by a private company. In January 1897 the company proposed that their lines should be electrified. The Streets Committee of the city council proposed modifications of the plan and recommended the council to insist that the company should obtain their electricity from the city's generating station. By September the committee were recommending the council to authorize the employment of a traction engineer to report on the advisability of taking over the tramways on the expiration of the existing lease in about five years' time, and on the cost of intro-

Plate 11 The Brooks oil-filled cable; a surviving sample of the cable actually used at Worcester in 1894
(Photo by M. Martin)

ducing electric traction. However, the council did not adopt the recommendation 'as they thought the proposal was premature'. But in April 1899 it was reported that the Streets Committee was to obtain expert opinion on those two matters. Messrs. Kincaid, Waller and Manville presented their report in July and advised the council to acquire and electrify the lines, at a total estimated cost, excluding generating plant and feeders, of £72,180. They estimated an annual car-mileage of 500,000 with receipts at 9*d*. per car-mile and working expenses at 6*d*. Allowing for interest and sinking fund, they expected a resulting net annual profit of £2,884. The council was recommended to oppose the proposals of the company to obtain power to retain possession of, and to extend, the tramways.

The Streets Committee found difficulty in deciding their attitude, but by December recommended the council to adopt the expert's advice. But the council decided otherwise, and negotiated an arrangement with the tramway company, whereby the latter would be allowed to go ahead with its extensions and electrification in return for a payment to the corporation of £5,000 and an undertaking to purchase their electricity from the corporation.

By April 1900, the British Electric Traction Company undertook to apply within a year for power to construct light railways from the Cross, in the centre of the city, to Cherry Orchard and on to Kempsey, to Red Hill, to Astwood Cemetery through Lowesmoor, to the city boundary on the Malvern Road and thence to Powick with a branch to the electricity works, and to the Henwick railway station. The existing lines from the Cross to Barbourne, St. Johns and Shrub Hill station were to be reconstructed. The whole would be worked by electricity, with a ten-minute service and fares of 1*d*. to the city boundary. Current was to be taken from the corporation at 2*d*. per unit for the first 200,000 units, then $1\frac{3}{4}$*d*. for 200,000 units, then the remainder at $1\frac{1}{2}$*d*.—subject to revision after fourteen years. The company would contribute £5,000 towards widening the High Street.

This satisfactory agreement led the Electricity Committee to consider how it could supply the large extra demand for electricity. There was no scope for further development at Powick, nor could it be economic to add more steam power there in view of the long feeders involved. It was therefore decided to negotiate for a site near the Severn for a new steam-driven station. This was finally settled during the early summer of 1901, the site being in Tybridge Street and Hylton Road, on the west bank of the Severn, and costing £4,450. The buildings and equipment were to cost £27,461. The tramways company were notified that current would be available for them by 1 December 1902, and the company apparently contracted to buy power as from that date.

However, by September 1902 the 'Worcester Tramways Ltd.' applied for an extension of time, blaming the council for some delay 'owing to the rejection by the Council of the scheme for double lines in the centre of the city'. However, the Tramways Committee (evidently a new committee) as far back as April had urged completion by July, so the council refused the extension. The new power station was opened on time, but the tramways failed to complete their work until January 1904. Thus, for over a year, the power station was unable to earn money to pay its costs, and the council sued the company for £1,666 13*s*. 4*d*., stated to be the value of the electric power contracted for but not taken. The company meekly agreed to settle for £1,500.

After 1902

The new power station was fully described in *The Electrician* for 22 May 1903. An interesting comment was that 'The steam plant at Powick can be shut down, as it will always be necessary to steam at the new station to supply the trams'. So Powick became a pure hydro-electric station.

Both stations continued in operation for a long time. That Powick was still thought of as useful even after World War I is indicated by the following report from *The Electrician* for 11 October 1918:

> Last week the Council adopted the Electrical Engineer's suggestion that he be empowered to accept the option given by Mr. Arthur Hicks for the purchase of the site, etc., of Bransford Mill, with the water rights, at £355.
>
> Mr. Hill said the purchase of these rights would enable them to develop, when desired, the water power at Powick. The Council also desired to acquire Nut Island in the same locality for £75.

By 1925 the energy generated at Powick represented less than seven per cent of the total generated in Worcester, and nothing had been done to develop the site. Powick was closed down in the late 1920s, the buildings being taken over by a laundry, which was certainly established there in 1928 as it is shown on the 25in OS map of that date. In the 1960s the buildings, still in good condition, were taken over by the firm of Fflow, General Engineers, making vehicle insulation, trailers and towing brackets.

Conclusions

Some general conclusions emerge from this study of early hydro-electric central stations. To make them of more general validity and interest, I will include where appropriate some information regarding the three other hydro-electric central stations built before the end of the century which were large enough to be significant, namely Fort William,[65] Salisbury,[66] and Monmouth.[67] For the first two, contemporary descriptions are available; and for Monmouth there is a reasonably-detailed modern history.

The installations at Godalming and Greenock were partially successful and were useful experiments, but they were 'before their time' and had little direct influence on the later systems. Wickwar was a rather special but trivial case which we need not consider further.

At most of the later stations trouble was experienced from inadequate water flow in summer and flooding in winter. In most cases some difficulty had been expected and steam standby plant provided. It is, however, clear that the difficulties had been underestimated; there had been far too much optimism about the amount of summer water flow, and the steam plant had to be used more than had been planned, thus increasing costs. At not one of the stations was there impounding or storage of any significant amount of water, although Lynmouth postponed the installation of engines for some time by the brilliant use of pumped storage. However, pumped storage is less efficient and probably more costly than direct impounding. There is no record of direct water storage being considered at any of the stations.

Another form of storage which was used in some of the later stations was the provision of secondary batteries or 'accumulators'. Both Fort William and Salisbury used them, and the former provided no engine standby. At times of low load the electricity generated by the water flow could be stored in the batteries, and then used to augment the supply when the load exceeded the capacity of the turbines. The use of batteries needed, of course, a direct-current supply, and of the stations mentioned here, only Fort William and Salisbury were based on dc. Monmouth, at a much later stage, was able to use battery storage, although its supply was ac, by coupling a dc dynamo to the alternator shafts and using it at times of low load to charge the battery; then at times of high load, the battery drove the dynamo as a motor and augmented the drive to the alternators.

Most of the schemes were hydraulically too unambitious, using rivers that were too small when larger rivers were available. At Worcester, as we have seen, the small River Teme was used because objections were raised to the use of the large River Severn; at Fort William, the little River Kiachnish was used at a point three miles from the town because the salmon-fishing interests had objected to the use of the closer and larger River Nevis; and at Monmouth the smaller River Monnow was used instead of the River Wye on the advice of the consulting engineer for reasons that do not appear to be on record.

In spite of their difficulties, both Worcester and Monmouth seem to have produced their electricity more cheaply than steam stations of similar size.

It is interesting to compare Worcester's concept of finding a day-load to use the daytime water flow (which was an economic failure) with Lynmouth's concept of storing the daytime water flow (which was relatively successful). In the long term, of course, day-loads had to come in large and/or industrial towns; but pumped storage still has a place in modern electricity systems as a means of coping with peak loads.

As a final point, the influence of tramway electrification at Worcester can be noticed. The extra load, and the fact that it had to be dc not ac necessitated the building of a new electricity generating station based entirely on steam; this removed the need of steam standby at the hydro-electric station which then became a pure hydro-electric station.

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6 *The Graphic*, 12 Nov. 1881.

7 Photograph no. 1027, Surrey County Library, Godalming Branch Library.

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10 *Engineering*, **33**, 13 Jan. 1882, 35-6.

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12 Notes on the minutes of the Town Council have been kindly supplied by Mr. K. W. Gravett; the minute books were unfortunately not available (due to Local Government reorganization) at the time of writing, but are now understood to be at the Guildford Muniment Room.

13 Information supplied by Mr. K. W. Gravett.

14 *The Electrician,* **12,** 5 April 1884, 485.

15 From minutes of Town Council.

16 *The Electrician,* **12,** 26 April 1884, 555.

17 See *The Electrician,* **25,** 1890, 601; **26,** 1891, 565; **35,** 1895, 796; **38,** 1897, 521; **39,** 1897, 524; **39,** 1897, 875; **40,** 1898, 531; **41,** 1898, 96; **41,** 1898, 301; **43,** 1899, 423; **43,** 1899, 579.

18 The first Scottish town to seek legal authority to set up a public electric lighting system was Irvine, as early as 1880; see *The Electrician,* **6,** 20 Nov. 1880, 2.

19 A very detailed description of the cable system is given in *Engineering,* **40,** 17 July 1885, 49-51.

20 *The Electrician,* **7,** 29 Oct. 1881, 369.

21 ibid, 370.

22 ibid, **11,** 2 June 1883, 50.

23 ibid, **13,** 23 Aug. 1884, 353-4.

24 ibid, **15,** 25 Sept. 1885, 381.

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48 *Electrical Review,* **151,** 22 Aug. 1952, 390, and 29 Aug. 1952, 461-2; *British Electricity,* Sept. 1952, 292-4; *Electrical Times,* 28 Aug. 1952, 355-6. NB Some of the historical information in these reports is almost certainly incorrect.

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50 *British Electricity,* Sept. 1952, 294.

51 *Elect. Engr.,* **6,** 14 Nov. 1890, 420.

52 ibid, 28 Nov. 1890, 490.

53 *Garcke's Manual,* e.g. vol. 16, 1912-13.

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55 Hellier (see ref. 30) states that this was the charge per quarter, but I think this must be an error. Both Garcke and *The Electrician* give the figure as £1 *per annum* per 16 candle-power.

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60 There is a discrepancy in the records at this point; the minutes of the Sub-Committee of the Watch Committee for 29 October 1891 say 4,071, but the report to the council says 'nearly 14,000'. The latter, being in accord with published reports, is more likely to be correct.

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