Hydroelectricity for public supply in Britain, 1881–1894

Prof. D.G. Tucker, D.Sc., C.Eng., F.I.E.E.

Indexing terms: *Electric power generation, Hydroelectric power stations*

Abstract

As it was the general nineteenth-century experience that water power was cheaper than steam power, it was natural that as electricity began to come into use for public supply in the 1880s, a good deal of development of hydroelectricity took place, especially in America and those countries of Europe where water power was more plentiful and coal rather scarcer than in Britain. It is interesting, however, that even in Britain there was some use of hydroelectricity. Numerous small, and later a few large, installations were made for private and industrial purposes, but there were or had been, by 1894, at least eight hydroelectric generating stations used for public supply. It is these stations that form the subject of the paper. Their early history and design is described, and some conclusions are drawn from their experiences.

1 Introduction and general background

Imperial units have been used in this paper as SI units would be meaningless in the historical context.

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. Electrical generators for the conversion of mechanical power into electrical power had developed slowly, from Pixii's crude machine of 1832 to the reasonably efficient dynamos of Gramme (1870) and Hefner Alteneck (1873), in response to the needs of science and the early technologies of electroplating and lighting by means of arc lamps. 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 by the introduction of the turbine around the middle of the 19th century. So, again, it was natural that where water power was available it should be applied to electricity generation. Hydroelectricity, as it later became known, was significant from the beginning in many countries, and still is. But in Britain 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 hydroelectric potential was all in the wrong places, i.e. remote from the towns. Consequently, hydroelectricity has never been really important in Britain. This is, no doubt, why its early history in Britain has been so neglected.

What is thought to have been the world's first hydroelectric installation was in England, at the private house of Sir William Armstrong, Cragside, near Rothbury in Northumberland, in 1880; it was used for lighting the then novel incandescent lamps developed locally, in Newcastle-upon-Tyne, by Swan. The world's first hydroelectric 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 also in England, at Godalming in Surrey.

After the beginning in 1880–81, hydroelectricity was adopted in numerous cases in Britain for the lighting of private mansions and mills etc. For the years 1880–1894 the author has found reports or records of at least 50 such installations. There must have been many others. For public lighting and consumer distribution in towns, however, the number of hydroelectric installations in Britain was small. For those same years, records have been found of only eight such stations, and, of these, only five really gave a public supply in the usual sense. In contrast, by 1894 there were, in Britain, at least 91 public-supply or 'central' stations driven by steam or gas engines, and, on average, they were larger. The hydroelectric stations, however, show more novelty and individuality.

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 hydroelectric.

The first eight hydroelectric installations for public supply in Britain appear to be 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

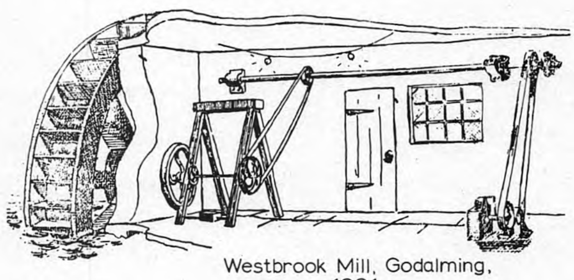

Fig. 1
Waterwheel and drive to dynamo at Westbrook Mill, 1881
[*The Graphic*]

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 stations of 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 great 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 records have been found of five hydroelectric 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; and Ingleton, February 1900.) Thus, it seems sensible to regard Worcester as the climax of 19th-century hydroelectricity for public supply.

Lest it be thought that Worcester was, in any sense, a climax also of hydroelectric engineering, it should be noted that far larger plants were already in operation in 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

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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 extended by the introduction of the turbine around the middle of the 19th century. So, again, it was natural that where water power was available it should be applied to electricity generation. Hydroelectricity, as it later became known, was significant from the beginning in many countries, and still is. But in Britain our useful 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 hydroelectric potential was all in the wrong places, i.e. remote from the towns. Consequently, hydroelectricity has never been really important in Britain. This is, no doubt, why its early history in Britain has been so neglected.

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After the beginning in 1880–81, hydroelectricity was adopted in numerous cases in Britain for the lighting of private mansions and mills, etc. For the years 1880–1894 the author has found reports or records of at least 50 such installations. There must have been many [illegible] public lighting and consumer distribution in towns, however, the number of hydroelectric installations in Britain was small. For these same years, records have been found of only eight such stations, and, of these, only five really gave a public supply in the usual sense. In contrast, by 1894 there were, in Britain, at least [illegible] public-supply or 'central' stations driven by steam or gas engines, and, on average, they were larger. The hydroelectric stations, however, show more novelty and individuality.

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Fig. 1
Pitt's wheel and drive to dynamo at Westbrook Mill, 1881

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Lest it be thought that Worcester was, in any sense, a climax also of hydroelectric engineering, it should be noted that far larger plants were already in operation in 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.

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Worcester station, therefore, has much in common with that of other municipal stations even though they were steam-operated, e.g. that at Bristol, opened a year earlier.[1] 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 hydroelectric problems, Worcester's story is much the same as the others in the list and it is analysed in some detail. More technological initiative was shown at Lynmouth, however, where what was probably the world's first pumped-storage hydroelectric system was introduced as part of an expansion programme in about 1895.

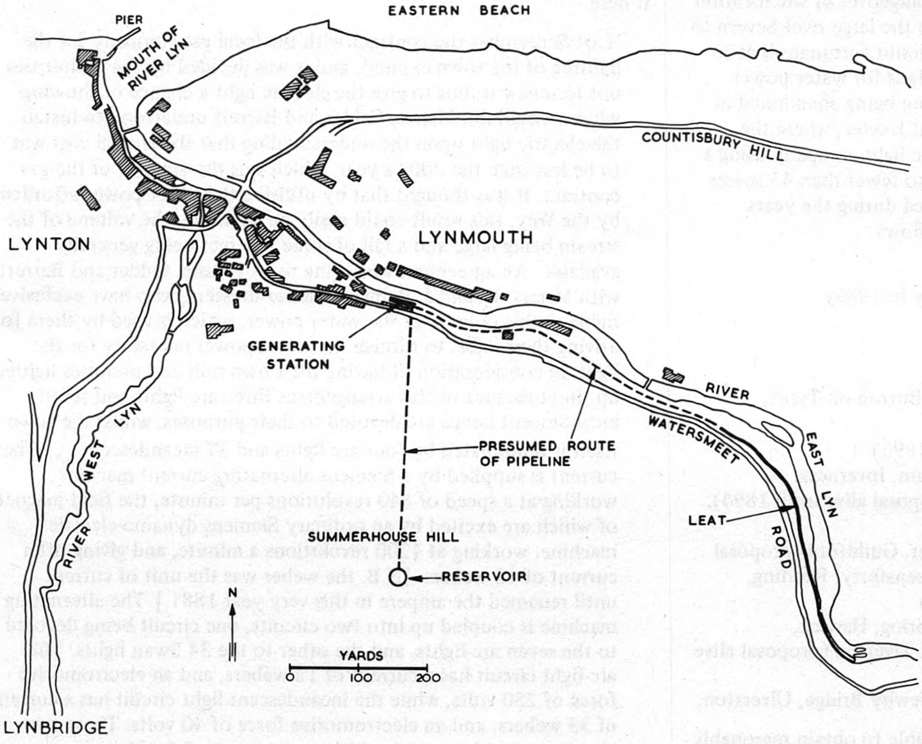

Fig. 2
Map of the hydraulic arrangements at Lynmouth

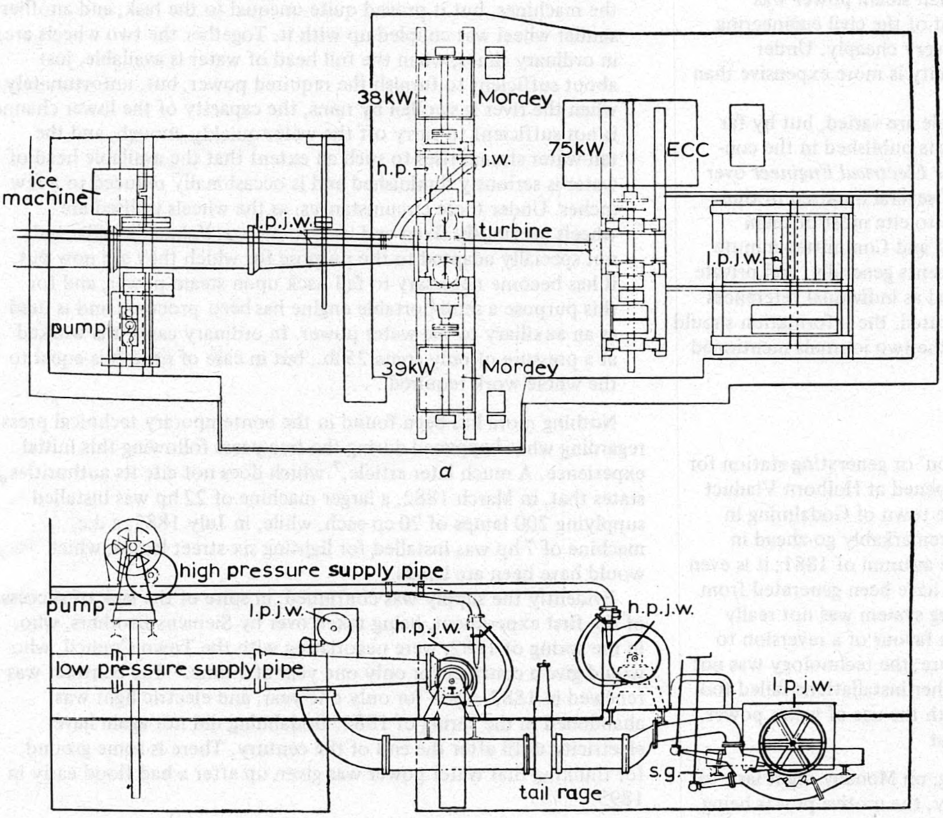

Fig. 3
Lynmouth generating station in 1899 [*Electrical Engineer*]

a plan of the works *b* elevation of the works
l.p.j.w. = low pressure jet wheel t = turbine
h.p.j.w. = high pressure jet wheel s.g. = speed gearing

It was the general 19th-century experience that water power, when available, was cheaper than steam power,[2] especially in places not very close to a coalfield. Thus, it is 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 available water power meeting even the initial needs of the station, e.g. at Bromsgrove in Worcestershire. 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. The author has records of no fewer than 45 towns in Britain where hydroelectricity 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 it has been possible to obtain reasonably reliable data (which for hydroelectric 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, hydroelectricity is more expensive than steam-generated electricity.

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. Use has been made 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.

2 Godalming, 1881

The first substantial 'central station' or generating station for the 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 2000) 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.

On 1 October 1881 it was reported[3] that

> 'An experiment was made at Godalming, on Monday night last, to light a portion of the town by electricity, the motive power 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 Pullman's leather mill, generally known as Salgasson's Mill or Westbrook Mill, at grid reference SU 967442. The mill no longer exists. A sketch of the water wheel coupled to the dynamo (reproduced here as Fig. 1) appeared in an article[4] on 12 November 1881.

A further report[5] in December gave later information and referred to two 'turbine wheels' being used. However, a full and detailed description,[6] 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*l* 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. R. 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 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. [N.B. 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 . . . . '

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,[7] which does not cite its authorities, states that, in March 1882, a larger machine of 22 hp was installed supplying 200 lamps of 20 cp each, while, in July 1882, a d.c. machine of 7 hp was installed for lighting six street lamps, which would have been arc lamps.

Evidently the supply was continued, in spite of the lack of success of the first experiment, being taken over by Siemens Brothers, who, in the spring of 1882, were negotiating with the Town Council, who would give a contract for only one year at a time.* The contract was renewed in 1883, again for only one year, and electric light was abandoned in the spring of 1884. Godalming did not again have electricity until after the end of the century. There is some ground for thinking that water power was given up after a bad flood early in 1893.

* 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 reorganisation) at the time of writing, but are now understood to be at the Guildford Muniment Room

3 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 authorised to develop an electricity supply.† 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, opened on 9th March 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.‡

The Electric Lighting Committee decided that Prof. Jamieson of Glasgow should be consulted over the tenders received in mid-1884. He also acted as consultant throughout the 'experiment', He evidently thought that Beckingsale's offer of £1040 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 9th March 1885. Prof. Jamieson had supervised the installation of the equipment and cables, and tested them himself, finding them to be entirely satisfactory.[8] There were 20 street lamps in the area. 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 charhouse with about 90 lamps.

The dynamos used (probably two in number) were Anglo-Brush Victoria machines, driven by ropes from a Gunther turbine.[9] 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 40 hp.[10] 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, and all laid underground.

Although the 'experiment' was evidently considered successful during 1885, it did not continue for long. An unsigned note in the *Electrical Review* for 24th June 1887, commenting on a vague note in the issue for 27th May, stated that the closure was solely due to the heavy charges for lamp renewals.

4 Wickwar, 1888

The public lighting of the little town of Wickwar, in Gloucestershire (population about 1000) was not a very ambitious undertaking and was only an offshoot of a private hydroelectric installation put into operation during the winter of 1887–88 by Arnold, Perret and 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 the 2nd October 1888 with 15 lamps, each of 32 candle-power, the furthest being three-quarters of a mile from the generator.[11]

By its fourth winter the system had been extended to 20 public lamps covering over a mile of road, and the town paid £15 p.a. for this.[12]

The motive power was an overshot water wheel 36 ft in diameter; the dynamo was a shunt-wound machine by Elwell and Parker, running at 550 rev/min.

5 Okehampton, 1889

Like the system at Wickwar, public electricity supply at the town of Okehampton in Devon (population around 3000) was an offshoot of a private installation. Mr. Henry Geen (who became the principal of the firm of Blatchford, Ash and Company) was a builder and timber merchant in quite a large business, and had installed a turbine to drive the machinery of his sawmill, using water from the East Okement river.[13] He also coupled to the turbine a 110 V d.c. dynamo of the Crompton 2-pole overpole type, and used the electricity to light the sawmill and possibly also to drive some motors.

In December 1888 it was announced:[14]

'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 5s 10d 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.[15]

The demand on Geen's public supply grew, and, in 1896, he supplemented the water power, which provided only about 8 kW, with a 50 hp. Worth-Mackenzie compound tandem vertical-condensing steam engine supplied by a Babcock and Wilcox water-tube boiler which was fired mainly by wood refuse from the sawmills blended with steam coal. This was later replaced by a 30 hp Crossley suction gas engine and suction gas plant. After the first world war, two 60 hp Gardner petrol/paraffin 4-cylinder direct-coupled generating sets were bought from the War Office. Still at the sawmill, and providing about 110 kW, this plant was taken over by the West Devon Electricity Supply Co. in 1930, and eventually dismantled when their new Mary Tavy hydroelectric station was opened in 1937. (This was, and remains, England's largest hydroelectric installation, although its installed capacity of 2.6 MW is small by Scottish and Welsh standards.)

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

6 Keswick, 1890

The main sources of information about this system are the journal *Electrical Engineer*, which published 27 short reports on the subject over the years 1889–1898; a paper in the *Proc. Inst. Civil Engrs.*;[16] a most useful interview with a former employee of the Company, Mr. Fred Armstrong, who joined as an engineman in 1924; and physical investigation on the site. The building which housed the generating station was still in existence in 1973.

The first announcement of the formation of a company to provide electric light in Keswick, using water power from the River Greta, was made on 22nd February 1889. On 1st August 1889 a statutory meeting of the company was held at which Mr. W.P.J. Fawcus, consulting engineer to the company, reported that the directors had accepted the tender of Johnson and Phillips of Charlton for the equipment of the station, 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 Frederic 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 1st October.

The opening was a little behind schedule, being on 7th January 1890, but otherwise all went well, and no hitches were experienced.

The station was built near Brigham Forge, on the site of an old woollen mill (grid reference NY 280240). The weir, and head and tail races, which had originally been provided for the mill, formed the basis of the power supply for the electricity station; but to increase the head of water to 20 ft, the tail race was lengthened from 70 to 100 yards and deepened by 4 ft. The head-race was improved a little by increasing its cross-section to 7 ft in width by 3 ft in depth.

The single 'Victor' horizontal turbine of 50 hp was built into the end wall of the head-race which served also as the wall of a bay of the station building. The stand-by steam engine, also of 50 hp, by Westinghouse, with two 10 inch single-acting cylinders and a 9 inch stroke, drove on to the main shaft, and clutches provided for the alternator to be driven by either the turbine or by both together. The alternator was a 30 kW machine to a design by Gisbert Kapp,[17] giving 15 A at 2000 V at a speed of 750 rev/min. The frequency was 75 Hz.

The mains were chiefly overhead wires with light insulating covering, relying for insulation from each other and from earth rather more on Johnson and 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. One short run of underground cable was provided, using the Brooks oil-filled iron-pipe system. Although the main distribution was at 2000 V, the supply to individual premises was at 100 V, 22 transformers being fitted at various locations to step the voltage down.

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 500 cp. 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.

It was not long before the company was making a loss. Nevertheless, they decided to apply for a Provisional Order so that they could lay underground mains in the streets. However, the Town Council opposed them and itself obtained an Order in April 1896. There was much bitter argument, but eventually, in June 1898 the Order was transferred to the Company.

† The first Scottish town to seek legal authority to set up a public electric lighting system was Irvine, as early as 1880; see *Electrician*, 1880, 6, p. 2
‡ A very detailed description of the cable system is given in *Engineering*, 1885, 40, pp. 49–51

The following year the whole of the shares and debentures were acquired by the Windermere and District Electric Supply Co.,[18] but the Keswick Electric Light Co. continued as a separate entity, under that name, until the system was closed down finally in January 1940.

It has proved difficult to obtain any reliable and consistent picture of plant developments before 1924. It is certain that a Gilkes 50 hp, vertical-shaft single Vortex turbine was supplied in 1898 and probably replaced the original Nell machine.* By 1909 there seems to have been a second turbine, and this may have been the Gunther 85 hp turbine (made by W. Gunther and Sons of Oldham) of which parts still remained in the building in 1973 and 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 85 hp.

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 25 kW and the other at 100 kW. 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 80 kW alternator, installed around 1927, and one of 200 bhp installed in 1934, both made by Mirrlees.

7 Lynmouth 1890

The water-powered electricity-generating station at Lynmouth, serving the twin towns of Lynmouth and Lynton in Devon, was opened in March 1890, only two months later than that at Keswick. It was, however, a larger and more interesting station than that at Keswick, 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 760 ft, and if it did have a supplementary steam-engine drive, this was certainly not provided before the very end of the 19th 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 a.c. supply at 100 Hz, until the great floods of August 1952 virtually destroyed it. There are very few remains of the system now to be seen.

The sources used for this history are, in the main, printed ones, comprising about 25 progress reports in the contemporary journals *The Electrician* and *The Electrical Engineer* between the years 1889–1900, together with References 19–22. 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; and Dr. R. Ferrer of Lynton has also been helpful.

The initiative for the provision of an electricity supply and electric lighting in Lynmouth and Lynton was taken effectively by a private individual, Mr. Charles Geen (a brother of the Mr. Henry Geen who had set up the electricity station at Okehampton). 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, 6 ft wide by 3 ft 6 in deep, for the first 400 yards, and finally a 30-inch iron pipe for 520 yards to the station (see the map of Fig. 2). The head at the turbine was about 90 ft. A horizontal-shaft reaction turbine of the 'Little Giant' type was used, made by Hett of Brigg in Lincolnshire; it could develop a power of around 150 hp. Two Mordey alternators were driven by the turbine on a single shaft; each could develop about 37·5 kW at 2000 V. 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.

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 Mr. H.H. Benn at the beginning of 1892. Evidently the growth of demand put Benn in some difficulty, and by the end of April 1894 he had sold out to a new company, the Lynton and Lynmouth Electric Lighting Co., who were stated to be prepared to generate more power and thus give a more efficient service. The new company's plans included not only new turbines and alternators, but also a pumped-storage system.

The Lynmouth pumped-storage system may well have been the first in the world used in connection with electricity generation. During periods of low demand, surplus electrical energy generated by the water turbine was used to operate a pump which lifted the water through a pipeline to a storage reservoir at Summer House Hill, some 800 ft above Lynmouth. The reservoir, 50 ft diameter and about 16 ft deep, had a capacity of 190 000 gallons. When the peak demand developed, the water in the reservoir was fed back through the pipeline to operate two 50 hp Pelton turbines. This pumped-storage system continued to operate until August 1952, when the station was destroyed by the tragic floods.

Basically, the new machineery was planned (*a*) to double the electrical generating capacity, and (*b*) to work with pumped storage. To achieve these ends, an additional alternator, of 75 kW, was installed, and four new turbines provided, so that the arrangement became as shown in Fig. 3. Here we have the following:

(i) in the centre, the original two Mordey alternators with the original reaction turbine centrally on the shaft between them, and in addition a high-pressure jet wheel (h.p.j.w.), or Pelton wheel. 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.

(ii) at the right, the new alternator, made by the Electrical Construction Co., with an h.p.j.w. 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.

(iii) 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 E.C.C. and Mordey alternators ran at different speeds, 480 and 640 rev/min, respectively. This necessitated two different h.p.j.w. designs, as the two h.p.j.w.s were directly coupled to their alternators. That on the E.C.C. alternator was 36 in diameter, with 24 buckets, each 2·5 in by 1·5 in, with two nozzles, each with separate control valves. That on the Mordey alternators was 30 in diameter, with 30 buckets also 2·5 in by 1·5 in.

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

At this period, the supply was commenced each day at 30 min before sunset and closed down at midnight. In December and January supply was given additionally between 6.30 a.m. and 9.00 a.m. There was no day-load, so that all day-time water flow was available, in principle, for storage.

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 about 440 kW (or more accurately, kVA). Two Parsons oil engines totalling 100 hp, fitted before 1923, were supplemented by a 100 hp 3-cylinder Ruston-Hornsby engine (installed new about 1929), a 160 hp 4-cylinder Sulzer engine (secondhand, about 1933), a 90 hp McLaren-Benz 4-cylinder engine (secondhand, about 1938), and a 165 hp 5-cylinder Ruston-Hornsby engine (secondhand about 1947); and a number of new and secondhand alternators were added. All this plant was still functional in 1952.

8 Chagford, 1891

The hydroelectric supply at Chagford, in Devon, was provided from a woollen mill, the water-wheel of which was used to drive a 20 kW alternator. In November 1890, the registration of the Chagford and Devon Electric Light Co. Ltd. was announced.[23] It had a registered office in London, and a capital of £2000 in shares of £1. Public lighting commenced on 1st September 1891 and, presumably, there were private consumers also. By 1900 there were the equivalent of 600 8 cp lamps connected, with 16 lamps for streetlighting.[24]

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

The company expanded financially, having, by 1922, expended over £7500 on plant, although there were still only 22 public lamps and 80 consumers.[25] The expenditure on plant included the purchase

* WILSON, P.N.: Private communication

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-voltage a.c. system and the water wheel as still in use in the 1920s, but Hellier[13] states that the system had become 200 V d.c. in 1911 and that a 30 hp turbine replaced the water wheel in 1914 and gave over 50 years service; indeed, it may still be in use. The old mill buildings no longer stand, and the generating station is housed in a separate small building. The company became part of the West Devon Electricity Supply Co. in 1930, and it is now still in operation, with an installed capacity of 26 kW, 3-phase a.c., under the CEGB and connected to the national electricity grid system.

The early history of the mills, part of which were converted for the electricity generating station, is given by Helen Harris.[26]

9 Worcester, 1894

The City of Worcester was the first municipality in Britain to build, and operate on a long-term basis, its own hydroelectric power station. This was, moreover, with a water-generated power of up to about 400 kW, by far the largest hydroelectric pcwer station built in Britain, in the 19th century, for public supply.

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 10 ft on the site where three old mills had stood. The station building still stands but is in use for another purpose.

The information given here 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*. In addition, the annual reports and accounts of the City Electrical Engineer have also been used, together with the minute books of the Worcester City Council and its various committees.

9.1 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, by September 1889, several companies had given notice to apply for Provisional Orders authorising them to supply electricity to the City, and, as a result, the City Council decided to take action and applied to the Board of Trade for a Provisional Order to authorise 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, and Mr. G.E.B. Pritchett of Oxford Street, London, was appointed to report on the best way of carrying it out.

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 Sherriff, 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. By October 1891, he had received 189 requests aggregating a load equivalent to 13 660 incandescent lamps of 10 cp. Consequently, tenders were invited for the construction of electric lighting works with a capacity of 12 000 10 cp lamps.

By March 1892, 15 tenders had been received and Mr. W.H. Preece, F.R.S., 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 reported within a fortnight, and the Town Clerk presented the following 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 6d 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. Buildings, street lighting etc. would cost another £19 970.

Brush proposed an a.c. system, which was supported by the Watch Committee but opposed at first by the Council who wanted a 'storage' system, i.e. d.c. with batteries. After a lot of argument, the Council, in June 1892, accepted a.c., but deferred acceptance of the Brush tender while the question of water power was further examined. 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 for the grant of a lease of the Powick Mills on the river Teme for 99 years at £160 p.a., or, alternatively, for the sale of the buildings and site for £5000. The Brush Company had reported on the best way of utilising the Powick site. So the Watch Committee decided to abandon the Diglis proposal.

By early December 1892 the Watch Committee had recommended, and the Council, after much discussion, had agreed, that Powick Mills should be bought for £5000, and that the revised Brush tender of a total of £23 209 should be accepted. 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 1500 hp, and turbines for upwards of 600 hp were to be installed at once, current being likely to be available early in 1894. The loan was sanctioned in June.

To make some use of the available flow of water by day, the pumping at the municipal waterworks was to be done by electric motors. Council voted £2089 for this purpose. This pumping load, during the first year or two of the operation, absorbed no less than 41·9% of the total power sold, and, being contracted at a price per kW/h below the cost of generation, led to some difficulties.

9.2 Construction and opening

A diagram of the site as developed is shown in Fig. 4, and a contemporary drawing of the facade of the building in Fig. 5. Work started in the late Autumn of 1893, and, despite serious setbacks, good progress was made; by August 1894 the opening date of 11th October 1894 was fixed – and it was adhered to! With a few private consumers the initial load was equivalent to nearly 5000 8 cp lamps (probably over 200 kW). It was supplied entirely by water power.

9.3 Technical description

No artificial mill pond was built, so that the only water storage was that in the headrace itself. This meant 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 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 125 kW alternators, marked 1–4 in Fig. 4, nos. 2 and 3 were arranged to be driven by 160 hp 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 60 hp turbine, or to a 100 hp turbine, or to both.

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

The turbines were of the mixed-flow type. Water flow through the turbines was controlled by a cylinder gate around the turbine wheel.

The four alternators were of the Mordey-Victoria type, rope driven at 430 rev/min, generating up to 58 A at 2200 V. They had stationary armatures and rotating field magnets, excited by two Brush-Victoria dynamos each of 5·83 kW, together with one of 6·5 kW. The first two exciters were driven from the shafts of two of the alternators, and the third by a separate small steam engine.

Switchboards were of Raworth's interlocked type. The high-voltage feeders from Powick to the distributing substation at All Hallows were of the Brooks oil-insulated type.[27]

9.4 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 246 912 kWh was supplied, but no less than 41·9% of this was for the waterworks motors. Although the commercial load of 143 268 kWh was charged at an average of 3·99d per kWh, only 1d per kWh was obtained from the Water and Sewerage Committee for the pumping load. This meant the total income from the pumping load was only £431.17s., a very small contribution to the total operating cost of £3057, to which had to be added £893 for interest and £952 towards the sinking fund. As the total earnings were £3254, this left a net deficit of £1549 on the year's working. It is not surprising that, in April 1896, Council decided to raise the charge to the Water and Sewerage Committee to 1½d per kWh.

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 551 437 kWh were sold, the station capacity having been increased (using more steam power) to 900 kW.

In spite of 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 2·97d 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 4·5d. This fell to 2·5d by 1899, but, by then, Worcester had fallen to 2·0d.

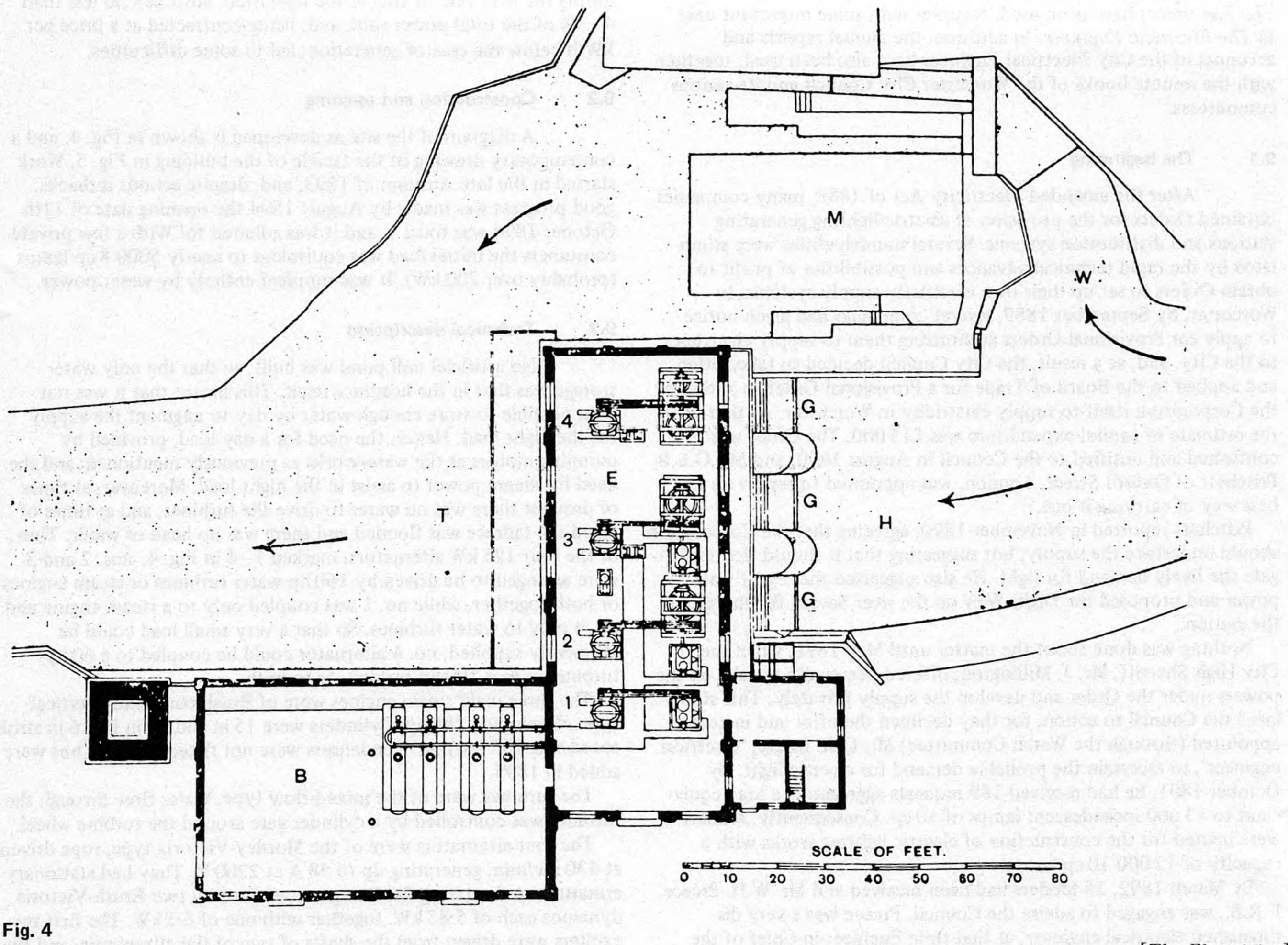

Fig. 4
Plan of Powick site [The Electrician]

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

9.5 Inadequacy of the water power and criticisms of the scheme

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

The electrical engineer's annual reports refer several times to a hydroelectrically 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 50% of the power being generated by water, only 41·7% 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, which the author has investigated. 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 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. Whether this would have been economic is another matter, now difficult to determine. On the other hand, a small storage reservoir, large enough only to store the day-time 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, 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 7s 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 £2000. For this, it should have been possible to provide storage of perhaps 5×10^6 ft^3., which at 6660 ft^3. 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.

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 as this load was never charged at anything like the cost of production – and the £2000 which the Council spent on motors for the waterworks would have paid for a reservoir anyway.

9.6 The city and the electrification of the tramways

The electrification of the tramways in Worcester is important in this context, as it resulted in the station at Powick becoming a pure hydroelectric station.

9.7 After 1902

The new power station was fully described in *The Electrician* of 22nd 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 hydroelectric station.

Both stations continued in operation for a long time. By 1925 the energy generated at Powick represented less than 7% 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 25 in O.S. 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.

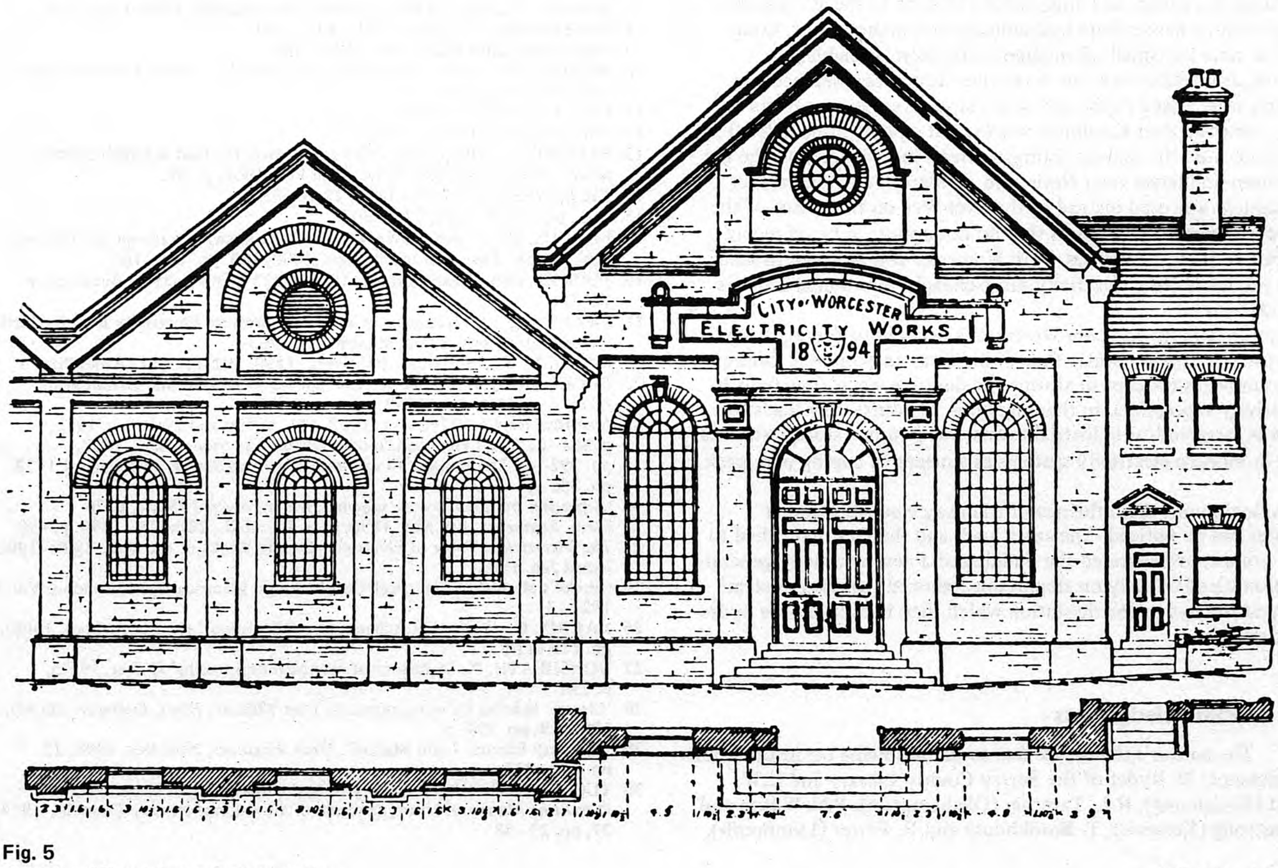

Fig. 5
Facade of Powick generating station [*Electrical Engineer*]

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. In spite of the Consultant's advice to take over the tramways, the Council eventually 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 £5000 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 greatly extended light railways. The whole would be worked by electricity, with a 10 min service and fares of 1d to the city boundary. Current was to be taken from the Corporation at 2d per unit for the first 200 000 units, then 1¾d for 200 000 units, then the remainder at 1½d – subject to revision after 14 years. The Company would contribute £5000 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 build a new steam-driven station, the site obtained being in Tybridge Street and Hylton Road, on the west bank of the Severn. The tramways company were notified that current would be available for them by 1st December 1902, and the company apparently contracted to buy power as from that date.

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 £1666 13s4d., stated to be the value of the electric power contracted for but not taken. The company meekly agreed to settle for £1500.

10 Conclusions

Some general conclusions emerge from this study of early hydroelectric central stations. To make them of more general validity and interest, I shall include, where appropriate, some information regarding the three other hydroelectric central stations built before the end of the century which were large enough to be significant, namely Fort William,[28] Salisbury,[29] and Monmouth.[30] 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 of '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 d.c. Monmouth, at a much later stage, was able to use battery storage, although its supply was a.c., by coupling a d.c. 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 engineers 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 a 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 d.c. not a.c., necessitated the building of a new electricity generating station based entirely on steam; this removed the need of steam standby at the hydroelectric station which then became a pure hydroelectric station.

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