

A Hundred Years of Electrical Engineering.¹

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IF any one event can be regarded as the birth of electrical engineering, it is surely the discovery by Faraday in 1821 of the principle of the electro-motor; that is, that a conductor carrying a current in a magnetic field experiences a force tending to move it. It is noteworthy that ten years elapsed before Faraday discovered, in 1831, the magneto-electric induction; that is, the principle of the dynamo. Four years later, Sturgeon added the commutator or "uni-directional discharger," as he called it, and in 1845 Cooke and Wheatstone used electromagnets, which Sturgeon had discovered in 1825, instead of permanent magnets. It was during the years 1865-1873 that the shunt and series self-excited dynamo, using a ring or drum armature and a commutator of many segments, finally evolved.

The early workers in the field do not appear to have realised the intimate connexion between the dynamo and the motor, for, although the principle was discovered by Lenz in 1838, it only appears to have become generally known about 1850 that the same machine could be used for either purpose. The principle underlying the whole modern development of electrical engineering, namely, the generation of electrical power by a dynamo, its transmission to a distant point, and its retransformation to mechanical power by an electric motor, appears to have evolved about 1873.

The development of the dynamo during the 'seventies and the simultaneous development of the incandescent lamp led to the general introduction of electric light during the 'eighties. Attempts to make incandescent electric lamps had been made so early as 1841, when de Moleyns patented one having a spiral platinum filament; and in 1847 Grove illuminated the lecture theatre of the Royal Institution with such lamps, the source of power being primary batteries; but it was not until 1878 that the commercial development of the incandescent electric lamp was begun by Edison and Swan.

One of the earliest complete house-lighting installations was put in by Kelvin in 1881. A Clerk gas-engine was used to drive a Siemens dynamo, a battery of Faure cells was fitted up, and every gas-light in his house and laboratory at Glasgow University was replaced by 16 candle-power Swan lamps for 85 volts. He had to design his own switches and fuses, etc., for such things were almost unknown.

For about twenty years the carbon-filament lamp held the field without a rival for interior illumination, and, although attempts were made to improve its efficiency by coating the filament with silicon, the plain carbon filament only gave way finally to the metal-filament lamp. One of the most interesting developments in the history of electric lighting was the Nernst lamp, which was introduced in 1897; the filament consisted of a mixture of zirconia and yttria, and not only had to be heated before it became conducting but also had to be connected in series with a ballast resistance in order that it might burn stably. The way in which these difficulties were surmounted and the lamp, complete with heater, ballast resistance, and

automatic cut-out, put on the market in a compact form occupying little more space than the carbon-filament lamp was, in my opinion, a triumph of applied science and industrial research. The efficiency was about double that of the carbon lamp. About this time, however, a return was made to the long-neglected metal filament. The osmium lamp invented by Welsbach in 1898 was put on the market in 1902, to be followed two years later by the tantalum and tungsten lamps. The latter was greatly improved by the discovery in 1909 of the method of producing ductile tungsten and by the subsequent development of gas-filled lamps in which the filament can be run without undue volatilisation at such a temperature that the consumption is reduced in the larger sizes to 0.6 watt per mean spherical candle-power. This improvement of eight times as compared with the efficiency of the carbon-filament lamp has led to the gradual replacement of the arc lamp even for outdoor illumination. The arc lamp was introduced at about the same time as the carbon-filament lamp, the Avenue de l'Opéra having been lit with Jablochhoff candles in 1878. The open arc was developed during the 'eighties; the enclosed arc, giving long burning hours and thus reducing the cost of recarboning, was introduced in 1893, and the flame arc in 1899. During the first few years of this century the flame arc was brought to a high stage of development and the consumption brought down to about 0.25 watt per candle-power, but the necessity of frequent cleaning to prevent the reduction of efficiency by dirt, and the labour of recarboning, have led to its abandonment in favour of the less efficient filament lamp.

Before leaving the subject of electric lighting I would point out that it is remarkable that the first great application of electric power should have been for the production of electric light, since it is probably the least efficient of all its applications. The overall efficiency of a small power station supplying a lighting load and having therefore a very poor load factor would not be greater than about 6 per cent. from coal to switchboard, the steam-engine being, of course, the principal offender. Of the total power supplied to and radiated from a carbon-filament lamp not more than about 2 per cent. was radiated as light, so that the overall efficiency from coal to light was 2 per cent. of 6 per cent., which means that of every ton of coal burned at the power station with the object of producing light all but about 3 lb. was lost as heat at various stages of the transformation. Even now, with up-to-date steam plant and gas-filled lamps, the overall efficiency from coal to light is not equivalent to more than 40 to 60 lb. of coal out of each ton. The electrical engineer may derive a little comfort from the knowledge that the purely electrical links are the most efficient in the chain.

Whilst on the subject of efficiency I might point out that the difference between the prices at which coal and electrical energy can be purchased by the ordinary citizen corresponds to the losses incurred in the power station; that is to say that the cost of the generation and distribution of the electrical energy is covered by

¹ From the presidential address to Section G (Engineering) of the British Association, Toronto, August 7.

the better terms on which the power station can obtain fuel. In Glasgow the writer pays 5*l.* per ton for anthracite to burn in a slow-combustion stove; taking the calorific value of anthracite at 9000 kilowatt-hours per ton, which is equivalent to 14,000 British thermal units per lb., this works out at 7½ kilowatt-hours for a penny. For electrical energy for heating and cooking purposes the writer pays a penny per kilowatt-hour. This ratio of 1 to 7½ will correspond fairly closely to the overall efficiency of the power station. In view of the high efficiency and convenience of slow-combustion stoves, it is evident that electric heating cannot be expected to compete with them for continuous operation; for intermittent heating the question is very different.

Returning from this digression to the development of the direct-current dynamo, it may be noted that the drum armature now almost exclusively employed was invented in 1872 by von Hefner Alteneck, and gradually displaced the ring armature of Pacinotti and Gramme. Although Pacinotti's original ring armature was slotted, smooth armatures were preferred for many years, until the mechanical superiority of the slotted armature caused the disappearance of the smooth core with its wooden driving pegs which were employed to transmit the turning moment from the conductors to the core. The commutator and brushes were a great source of trouble, but by the gradual elimination of unsuitable material and by better design and methods of manufacture the commutator has been made a most trustworthy piece of apparatus. The difficulties of commutation, and especially the need of continual adjustment of the brush position, were largely overcome by the invention of the carbon brush by Prof. George Forbes in 1885. It should be pointed out that the commutating poles, which have come into use so much in recent years, were originally suggested in 1884, and are therefore older than the carbon brush.

The realisation of the idea of supplying electric current from a power station for lighting houses in the neighbourhood owed much to the energy and business ability of Mr. Edison. He exhibited his first "Jumbo" steam-driven dynamo in 1881, and installed two sets at Holborn Viaduct in the following year to supply current to neighbouring premises. The output of these sets was about 90 kilowatts at 110 volts, which was so much larger than anything previously constructed that the name "Jumbo" was applied to these sets. About 1890 the multipolar type began to replace the bipolar type for the larger sizes. The size of the single units employed in power stations gradually increased with the increasing demand, and by 1895, dynamos of 1500 kilowatts had been installed.

Ferranti was apparently the first to suggest that the power station should be outside the city, at a point convenient for fuel and water supply, and that the power should be transmitted into the city by high-voltage alternating currents. In 1890 he built the Deptford Station for the London Electric Supply Company, and installed 1000-kilowatt 10,000-volt alternators. This was the pioneer high-voltage underground cable transmission, and much was learnt concerning the peculiarities of alternating currents when transmitted over cables of considerable capacity. The following year, 1891, saw the first long-distance trans-

mission by means of overhead conductors in connexion with the electrical exhibition at Frankfort-on-Main; three-phase power was transmitted, at 8500 volts, from a water-power station at Lauffen to Frankfort, a distance of 110 miles.

This development of the use of high-voltage alternating currents followed the development of the transformer. Gaulard and Gibbs patented a system of distribution involving transformers in 1882, and, although their patent was upset in 1888 on the ground of its impracticability, the present method of using transformers for the distribution of electrical power was introduced in 1885, and shown at the Inventions Exhibition in London in that year. Although from 1890 onwards there has been a steady increase in the size of alternators and transformers and in the voltage employed for long-distance transmission, the last few years have seen a really amazing increase in the size of the units employed. In 1913 the largest 2-pole turbo-alternators had an output of 3000 revs. per minute of about 7500 kilowatts; such machines are now made up to 30,000 kilowatts, and 4-pole alternators are running at 1500 revolutions per minute, with an output of 60,000 kilowatts. This increase in size and in peripheral speed has been made possible by improvements, both in the material and in the design. With a bursting speed 25 per cent. above the running speed, the peripheral speed can now be raised to 150 metres per second. Improved methods of cooling and a better understanding of the various causes of loss in the armature have enabled the materials to be used at higher current and flux densities.

This great increase in the size of units is not confined to the steam turbo-generator, as can be seen from the water-turbine sets recently added to the Niagara installation. Whereas the original Niagara turbines were of about 5000 horse-power, the new ones have an output of 70,000 horse-power at the low speed of 107 revolutions per minute.

The importance of cheap electric power has led to this great increase in the size of the units in the generating stations. Any slight difference of efficiency between a 10,000-kw. and a 60,000-kw. alternator is of little importance, and would certainly not counterbalance the decreased factor of safety due to concentrating the whole power supply in three or four large units, instead of distributing it between a dozen or more units. The reason for the adoption of the smaller number of large units lies almost entirely in the decreased capital cost per kilowatt of plant. In my opinion, however, there are many cases in which too much consideration has been given to this factor, and too little to the importance of a guaranteed continuity of supply.

Until recently, the only means of producing a large amount of high-voltage D.C. power was by connecting a large number of carefully insulated dynamos in series, as in the well-known Thury system of power transmission. Within the last two or three years another method has been developed, viz., the so-called transformer, which consists of an arrangement of transformers and a system of rotating brushes, whereby a three-phase A.C. supply is converted into an almost steady continuous current. The first apparatus of this type to be exhibited is installed at the British Empire Exhibition at Wembley, and is designed to deliver

continuous current at 100,000 volts. It can also be used for the reverse process. It would thus enable a three-phase generating station and a three-phase sub-station to be connected by a direct-current transmission line, thus avoiding not only the maximum voltage of 1.4 times the effective voltage, which was one of Lord Kelvin's objections to the A.C. system, but also all trouble due to the capacity and inductance of the line.

Electric traction represents one of the most important branches of electrical engineering. It shares with the petrol motor the distinction of having absolutely revolutionised the methods of transport within a single generation. In its origins it is nearly a century old, for attempts were made in the 'thirties to apply Faraday's newly discovered principle to the propulsion of vehicles, but, with very primitive motors and primary batteries, these attempts were doomed to failure. The development of the dynamo and motor in the 'seventies opened the way to further experiments, and at the Berlin Exhibition in 1879 a line one-third of a mile long was shown in operation, a locomotive drawing three cars. The first regular line was opened to traffic near Berlin in 1881; it worked at 100 volts and the current was collected from an insulated rail. Toronto was the scene of one of the earliest experiments in America; C. J. van Depoele, after some experiments at Chicago in 1882 and 1883, ran an electric locomotive in 1884 between the street-car system and the Exhibition in Toronto.

The difficulties were enormous. The carbon brush was not invented until 1885, and commutation in a reversible motor with copper brushes caused great trouble; armature construction and winding was in its infancy; the suspension of the motor and the method of gearing it to the car axles were problems which were solved only after much experience. Rapid progress was made after about 1887, and the closing years of the century saw an enormous development, the elimination of horse tram-cars throughout the world and the electrification of a number of city and suburban railways.

Of the various systems of collecting the current, only two have survived for street-cars, namely, the usual overhead wire and the exceptional underground conduit; in the case of railways there is no necessity for a conduit, and the conductor rail is carried on insulators above the ground-level.

Although 500-volt D.C. supply has been standardised for street tramways, the relative merits of D.C. and A.C. for electric railways has been a burning topic for more than twenty years, and is now perhaps more burning than ever. It is somewhat akin to the battle of the gauges in the early days of steam railways, for it involves in many cases the problem of through-running, if not now, in the not very distant future. Although the three-phase system was successfully installed in Northern Italy, it has grave disadvantages, and the battle now is confined between direct current at an increased voltage of, say, 1500 to 2000 volts, and single-phase alternating current. In the latter case there is, moreover, a further question as to the best frequency to adopt, this being usually either 25 or 16 $\frac{2}{3}$. The development of the A.C. commutator motor to the stage where it was applicable to traction took place during the first few years of this century, and, although

in itself it is inferior to the D.C. motor, it introduces so many simplifications and economies in the transmission of the power from the generating station to the train that experts are very divided as to the relative merits of the two systems for main-line electrification.

I can only refer briefly to the applications of electrical power to chemical and metallurgical processes. Some of these are purely electro-chemical, others are purely thermal, while in many processes the electric current performs the double function of melting and electrolysing. The possibility of electroplating was discovered so early as 1805, but the commercial application of electro-chemistry on a large scale was impossible before the development of the dynamo. Within the last thirty years the provision of an abundant supply of electrical power has led to the creation of enormous electro-chemical industries; I need only instance the production of aluminium, carborundum, and calcium carbide. These industries have usually been established near a hydro-electric plant and provide a load of very high load-factor.

I turn now to what may be called both the earliest and the latest application of electricity; that is, its use for transmitting intelligence. One of the greatest factors in the development of our modern life has undoubtedly been the network of wires and cables which has spread over the whole earth, making possible an almost instantaneous transmission of intelligence and interchange of opinions. In the early days of electrical science the discovery of a new property of electricity was followed by attempts to utilise it for this purpose. So early as 1746 there are records of the use of frictional electricity for the purpose, and distances up to four miles were tried. In 1774 Lesage of Geneva proposed 26 wires in earthenware pipes with pairs of pith-balls at the end of each wire, which flew apart when the conductor of a frictional machine was brought near the other end of the wire. A current of electricity was unknown until Galvani's discovery in 1789, and Volta's pile was first constructed in 1792. Carlisle in 1800 found that water was decomposed by passing the current from a Volta pile through it, and this was the basis of the telegraph proposed by Sömmering in 1809, in which 26 wires ended in 26 metallic points arranged in a row along the bottom of a kind of aquarium. By means of a lettered keyboard at the sending end the current could be applied to any wire, and a stream of bubbles caused to rise from the appropriate point, each point being duly labelled with its appropriate letter. The magnetic effect of the electric current was discovered in 1819, and immediately replaced the previous methods in efforts to develop an electric telegraph; except for the attempts to make a high-speed chemical telegraph, all subsequent telegraph systems have employed the magnetic effect of the current. A great many of the fundamental inventions of telegraphy were made in the 'thirties; the list includes the needle instrument of Cooke and Wheatstone, the sounder of Henry, the dot-and-dash inker of Morse, and the use of the earth as a return by Steinheil. Although the needle instrument is now obsolete, the sounder and Morse inker are still commonly employed. Many have been the devices for increasing the amount of traffic which can be worked over a single line, either by the simultaneous use of the line by a number of

operators, as in the quadruplex and multiplex systems, or by punching the messages on paper tapes, which can then be fed into an automatic transmitter working at a speed ten to twenty times that attainable by a manual operator. In the most up-to-date systems the perforation of the tape is done by the operators working an ordinary typewriter keyboard, and the received message is printed in ordinary type, a single wire carrying eight messages simultaneously, four in either direction, at a speed of 40 words per minute.

The need for telegraphic communication between countries separated by water was so much the greater because of the slowness of other means of communication, but the difficulties in laying and maintaining 2000 miles of insulated wire on the bottom of the sea must have appeared almost insuperable to the early workers; fortunately, however, there were men who had the necessary vision and courage. The flimsiness of the early cables suggests that the pioneers underestimated the magnitude of the problem which faced them, which was perhaps fortunate. A cable was laid between Dover and Calais in 1850; it lived only a single day, but it was replaced in the following year by a successful cable.

The first cable was laid across the Atlantic in 1858, and, although in the light of our present knowledge we know that it could not have had a very long life, its failure after a few weeks of preliminary communication was primarily due to misuse owing to the ignorance of those in charge. Although much costly experience had been gained in the laying of cables in various parts of the world since this first attempt to span the Atlantic, the success of the second Atlantic cable in 1866 was largely due to the scientific ability of Kelvin and to his untiring application to the project at every stage of the manufacture and laying of the cable.

Turning to another branch of electrical communication, it is no exaggeration to say that modern business life has been revolutionised by the telephone, which will shortly celebrate its jubilee, for it was in 1876 that Graham Bell invented the magnetic telephone receiver, although others, notably Reis, had been working at the problem since 1861. Bell showed his telephone in operation at the Philadelphia Centennial Exhibition in 1876, and Kelvin, who was one of the judges, brought one back with him and demonstrated it to Section A of the British Association, at its meeting in Glasgow in the autumn of 1876.

A successful telephone system requires much more than efficient transmitters and receivers, and the great development which has taken place has been largely a matter of improvement in the design of the many elements that go to make up a telephone exchange. The modern manual central-battery exchange, in which one has only to lift his receiver to call the operator and be connected in a few seconds to any one of 10,000 other subscribers, is a marvel of ingenuity and construction. But this is now gradually being replaced by the greater marvel of the automatic system, in which the operator is eliminated and the subscriber automatically makes his own connexion to the desired subscriber. Attention should be directed to two outstanding inventions in the actual transmission of telephony over long distances, namely, loading and repeaters. It was Oliver Heaviside who in 1885 proposed

to improve the range by increasing the inductance of the line. Although this revolutionary suggestion fell on deaf ears for fifteen years, it ultimately proved to be one of the great inventions of telephony; it is of special importance in underground and submarine telephone cables, the electrostatic capacity of which otherwise seriously limits the range. The other outstanding novelty is the introduction of repeaters at intermediate points in long telephone lines. These repeaters are specialised types of low-frequency amplifiers; they were made commercially possible by the invention and perfection of the three-electrode thermionic valve. The attenuated speech currents arriving at the end of a section of line are amplified and thus given a new lease of life before being passed on to the new section. By using a large number of such repeating stations, telephonic communication has been established between New York and San Francisco.

Turning now to radio telegraphy and telephony, one cannot but marvel at the rapidity of its development and the inroad that it has made during the last two or three years on the domestic life of the whole civilised world. The theory of Clerk Maxwell in 1864 and the laboratory experiments of Hertz in 1888 found their first practical application in Marconi's Italian experiments in 1895 and his demonstrations in England during the following year. Much of the rapid progress was due to his perseverance, vision, and courage in perfecting apparatus for short-distance work, and simultaneously experimenting over long distances, and thus, in the year 1901, settling by actual demonstration across the Atlantic the vexed question as to whether the waves would pass around the earth over distances of several thousand kilometres or go off into space.

The accomplishment of long-distance communication bristled with difficulties, largely due to unsuspected atmospheric effects which are still little understood; but such progress has been made and is continually being made that one dare not now adopt an incredulous attitude to the wildest dreams or forecasts of what is to be accomplished by "wireless." The commonplace facts of to-day would have appeared beyond the bounds of possibility ten or twenty years ago.

By the aid of electricity the energy of the coal or of the lake or river a hundred or even two hundred miles away is transmitted noiselessly and invisibly to the city, to supply light and warmth, to cook the food, to drive the machinery, to operate the street-cars and railways. By its aid one can flash intelligence to the most distant part of the globe, hold conversations with friends hundreds or even thousands of miles away, or sit in one's home and listen to music and lectures broadcast for the entertainment or instruction of all who care to equip themselves with what may almost be regarded as a new sense. Whereas thirty years ago a ship at sea was completely isolated from the life and thought of the world, it is now in continuous communication with the land and with every other ship within a wide range. In no branch of electrical engineering, however, is there any suggestion of having reached finality; on the contrary, rapid development is taking place in every direction, and we can look forward with confidence to an ever-increasing application of electricity to the utilisation and distribution of the natural sources of energy for the benefit of mankind.