ELECTRIC POWER - I

Volta announced the discovery of the "pile" or battery in 1800, and this may be taken as the beginning of electric power. Steady direct current was now available. But it was three-quarters of a century before electric power in a commercial form was available. This was because battery power was too expensive to be of very great commercial value, and commercial and industrial electricity had to await developments in electro-magnetism.

It was suspected before Volta's discovery that electricity and magnetism were related. It had been observed that

(a) magnetism and static electricity both had two polarities.

(b) the inverse-square law operated for both (although so it did also for gravitation)

(c) compass needles could be weakened or reversed by lightning.

So naturally Volta's pile led to a new burst of experiment. But no definite results were obtained until Oersted's great discovery in 1820. This was, in a sense, a chance discovery, for it did not result from a logical process of deduction; but Oersted had been working in the subject for a long time and it was only because he had the right apparatus that the discovery was made. Probably most great discoveries are like this.

It had always hitherto been thought that it was the voltage (as we now call it) that was responsible for all electrical effects, and the nature of current was not understood. So it was "by chance" that Oersted, in the course of a lecture to advanced students in Copenhagen, actually closed the electrical circuit from a battery through a conductor passing close to a magnetic needle. He observed the resulting movement of the needle, and immediately recognized the importance of his observation. It is said that with trembling hands he invited the students to try the experiment for themselves.

Oersted continued his experiments and published the results on 21st July 1820 - in Latin, with the title "Experimenta circa effectum conflictus electrici in acum magneticam". He described the importance of having a closed circuit, and how he got a larger battery made for him. What happened in the battery and in the space surrounding it he called the "conflict of electricity". With the conductor above and parallel with the needle, the end of the needle nearest the negative pole of the battery moves towards the West. With the wire under the needle, the needle moved in the opposite direction. Oersted had deduced the nature of electromagnetism quite shrewdly, for he wrote (translated into English not long after) :-

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"Electric conflict can only act upon magnetic particles of matter. All non-magnetic bodies seem to be penetrable through electric conflict; but magnetic bodies, or rather their magnetic particles, seem to resist the passage of this conflict, whence it is that they can be moved by the impulse of contending forces. That electric conflict is not inclosed in the conductor, but as we have already said is at the same time dispersed in the surrounding space, and that somewhat widely, is clear enough from the observations already set forth.

"In like manner it is allowable to gather from what has been observed that this conflict performs gyrations, for this seems to be a condition without which it is impossible that the same part of the joining wire, which, when placed beneath the magnetic pole carries it eastward, drives it westward when placed above; for this is the nature of a gyration that motions in opposite parts have an opposite direction".

Many experimenters followed up this work, including Humphrey Davy who used iron filings to demonstrate that the magnetic effect of a current in a conductor depended on the flow of electricity through it, Arago and his disc (a magnetic needle followed a rotating copper disc through the action - discovered later - of eddy currents), and Ampere. Within 7 days of hearing the results of Oersted's experiments, Ampere communicated a paper to the Academy of Sciences in Paris describing his experiments and conclusions. He included:-

(a) the law for determining the position taken up by a needle relative to the conductor and direction of current.

(b) the demonstration that the current flowed also through the battery and that thus there was a complete circuit.

(c) a prediction that coils of wire carrying current would act as magnets.

(d) the idea of the astatic needle (a pair of coupled needles mounted parallel but with opposite polarity, one above and one below the conductor, so that there was no effect from earth's field)

(e) the idea that not only should current affect a magnetic needle, but that conductors carrying current would affect each other.

(f) the idea that these effects were separate from the attractions and repulsions of static electricity (as we now call it). He also derived mathematical formulae for some of these effects.

Discoveries continued, e.g. Schweigger's multiplier (later called galvanometer), where a multi-turn coil magnified the effect of

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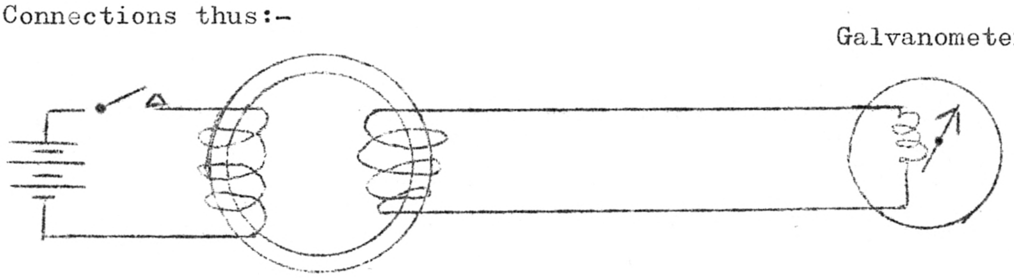
of a current on a needle; Sturgeon's electromagnet, using a horseshoe iron with copper winding on its arms, lifting 9 lbs at first attempt. (By 1830, Joseph Henry could lift 3,500 lb this way.) But no-one then understood the effect of internal resistance in a battery, although rules for the best way to connect a multiplicity of cells were made. Ohm enunciated his famous law in 1826, but it had a very small impact for a long time.

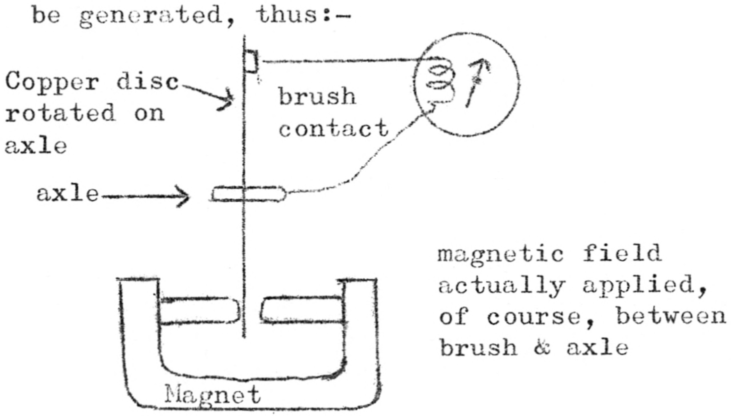
It was Michael Faraday who had the greatest impact on the new science at this time. He was interested mainly in chemistry, and his electrical work was done in two bursts, one in 1820-1 following Oersted's discovery, and the other in 1831. During the first period, Faraday demonstrated that a magnetic pole would move round a conductor carrying current, and also that a conductor would move round the magnet.

During the second period he discovered that
(a) in a toroid of iron with two coils of insulated wire, the <u>connection</u> of a battery to one coil produced a transient current in the other when it was connected to a loop of wire; similarly the <u>breaking</u> of the connection to the first coil caused a transient current in the other.

Connections thus:-



(b) thrusting a bar magnet into a cylindrical coil of wire connected to a galvanometer caused a transient current; similarly on withdrawal.
(c) by extending Arago's disc experiment, powerful continuous currents could be generated, thus:-



Thus Faraday had, in effect, laid the foundation for
(a) the transformer
(b) the alternator
(c) the continuous electromagnetic generation of direct current.

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ELECTRIC POWER - II

Summary of Development of Dynamo

1831 Faraday's great discovery and experiments (transformer, alternator, d.c. generator: foundations)

1831 dal Negro of Padua: reciprocatingly-driven manual generator

1832 Hypolite Pixii of Paris: generator using rotating horseshoe magnet, 3000 ft of wire on coils, gave powerful shocks - he later that year added a commutator (first ever).

1833 Saxton (at Brit.Ass.meeting in Cambridge) showed a generator using 12 horseshoe magnets, soft-iron cross as armature; coils of different numbers of turns giving lower voltage for shocks and higher voltage for sparks.

1833-6 Edward M. Clarke, instrument maker of London, made and developed Saxton machines. Reported powerful shock on separating output wires after they had been short-circuited; thus effectively discovered self-induction.

c.1835 Wm.Sturgeon used shuttle-type coil revolving between (as opposed to "against") poles of magnet "so as that the wire may strike, at right angles, the most formidable group of magnetic lines". He also made the first metallic solid commutator (early ones were wires dipping in mercury).

c.1840 Stöhrer of Leipzig introduced multipolar machine, to reduce vibration. His model used 6 poles from 3 horse-shoe magnets with armature comprising 6 coils and a commutator.

c.1842 Woolrich produced a continuous (as distinct from intermittent) d.c. by using more coils than magnets and taking current from coils at peak. This was used for electro-plating which was by then an important industrial process.

1850 Nollet of Brussels patented steam-driven improved Stöhrer machine.

1851 William Millward of Birmingham patented machine with 8 horseshoe magnets arranged in a circle, and an armature of 16 bobbins.

1852 Nollet patented improvement to Millward's machine so that the 16 poles were in a circle.

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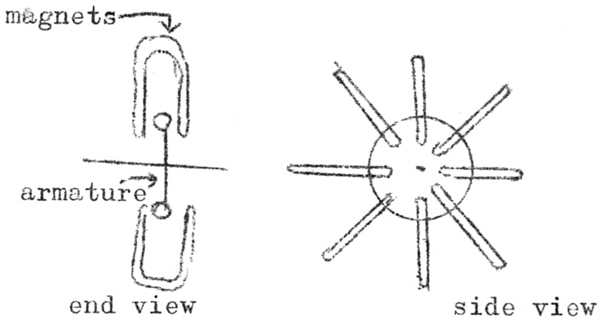
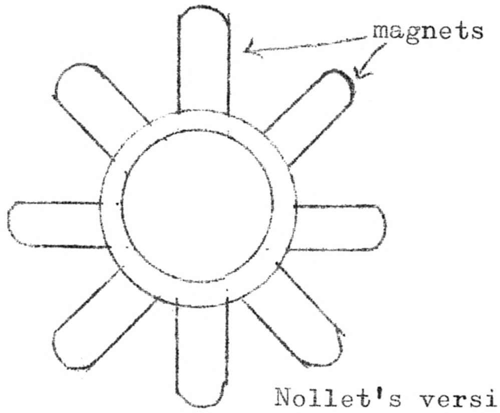


Millward's
machine



Nollet's version

N.B. At this time the main interest was in lighthouse illumination. Nellet thought of using limelight - block of lime heated to incandescence by oxyhydrogen flame, oxygen and hydrogen being obtained by electrolysis of water. The next development was to use arc-light, and a machine was needed to generate the electricity for this. So we reach:-

1856 - 8 Frederick H. Holmes, an English professor, developed a large machine using 36 horseshoe permanent magnets which rotated while the "armature" coils were stationary. Weight 4000lbs, produced 1500 W at most. Trials for Trinity House took place at Blackwell in 1857 under the supervision of Faraday acting as consultant to T.H. They were successful, so Holmes built two machines for South Foreland lighthouse, but this time used rotating coils (80 of them on two wheels rotating at 90 r.p.m. driven by steam engine) and stationary magnets. The arc light was projected over the sea for the first time on 8 December 1858. Holmes got many more orders - his 1862 design ran for 13 years and two machines built in 1867 (generating A.C.) remained in service until 1900.

c.1866 - 7 Carl Wilhelm Siemens (later called William Siemens) originally of Hanover but now resident in England; Charles Wheatstone (London professor) and S.A. Varley; and Henry Wilde (also English) - all developed machines using electromagnets instead of permanent magnets. The idea was to use a small machine (with a small amount of permanent magnetism) to provide the current for the field of a larger machine - and the process could be continued to get even larger machines. Wilde probably got the most suitable design for commercial use. He (like the others) also developed self-excitation in 1866 - 1867. But in all machines up to this time fluctuation of the output current was a nuisance:-

1870 Zénobe Théophile Gramme, a Belgian, invented (or rather, re-invented an idea suggested about 1860 by Pacinotti) a machine which gave a continuous output through the use of the ring-wound armature. This was really the turning-point in industrial development of electrical machines. Numerous Gramme machines were made and they remained in use for a long time.

1873 Hefner Alteneck invented the drum winding. In the Gramme winding the inner part of each turn of coil was not only useless; it in fact reduced the output. Alteneck saw that the solution was not to have an inner part, but instead to connect suitably single conductors laid longitudinally on the surface of a drum. This led to the modern kind of armature winding.

Electric power had arrived. People like Crompton, Hopkinson, Ferranti, Edison developed it. The electric light made a market for it. First the arc-light, gradually improved; then the incandescent-filament lamp from about 1878-80, developed at first independently by Edison and Swan (Joseph Wilson Swan of Newcastle, 1828-1914), then jointly.

Electric traction also developed. The first electric railway was demonstrated by Siemens and Halske in Berlin in 1879. In 1880 Edison built an experimental railway in his grounds at Menlo Park. Apart from minor railways the main application of electric traction was to street tramways, from about 1890 onwards. By 1914 there were 264 electric tramway undertakings in U.K. alone. The City & South London electric tube railway was opened in 1890.

It is an interesting fact of electrical history that the idea that a generator could also be used as a motor dawned very slowly and late. It was not until 1873 that the idea really got established. All early effort was turned to generating electricity; until it could be economically generated, there was comparatively little interest in using it.

Electricity generation for public supply started around 1882-3.

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GROWTH OF ELECTRICITY PRODUCTION

U.K.

Yesr	No. of stations	installed capacity	Units generated
1907		1,020 MW	1,432 x 10^9 KWh
1922	426	3,094	4.572
1930	483	6,946	10.948
1939	365	9,712	26.814
1946		12,498	41.253

Other countries in 1947	Installed capacity
U.S.A.	51,000 MW
Germany	23,800
U.K.	12,500
France	9,600
Italy	6,500
Belgium) Holland) Denmark)	5,500
Norway	2,350

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