CENTENARY OF THE TRANSFORMER

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Summary

K. Zipernowsky, M. Déri and O. T. Bláthy, engineers of Ganz Works in Budapest, field their patent applications in January—March 1885 concerning in-parallel connection, freely chosen transformer ratios and closed-core transformers. The term "transformer" was also used by them for the first time. This paper deals with the antecedents and the story of the invention.

On May 1, 1985 the Hungarian electric power industry celebrated a centenary of great importance: 100 years ago the operation of the first commercial transformers suited for practice was started at the National Exhibition in Budapest.

The experimental work leading to the development of closed-core transformers and the principle of in-parallel connection of transformers was started in the summer of 1884 in the Electrical Department of the Ganz Company, Budapest.

The experiments and the world success of the transformers following their presentation at the exhibition were, of course, not without antecedents.

It was the English physicist Michael Faraday who laid the foundations on August 29, 1831 by discovering electromagnetic induction. The device he used consisted essentially of a closed iron core surrounded by two windings. When the direct current flowing in one of the windings was interrupted, he observed a voltage surge across the terminals of the other winding (Fig. 1a).

Independently of Faraday, Joseph Henry carried out similar experiments at the Academy in Albany, New York State, and succeeded to draw a spark between two electrodes by interrupting the circuit of a solenoid (Fig. 1b).

J. C. Page in Washington, D. C., established in 1836 that sparks can be produced across tappings of a solenoid by interrupting its circuit (this is the principle of the autotransformer) (Fig. 1c).

The following year, N. J. Callan, an English priest, interrupted the current flowing in one of two coils linked by induction only and thus produced sparks across the terminals of the other coil (Fig. 1d).

Ruhmkorff developed a spark inductor in Paris, in 1851. This apparatus allowed to transform the low voltage of galvanic cells into high voltage.

To obtain a more powerful spark, C. F. Varley reversed the direction of the direct current at each switching. Also, he was the first to propose the

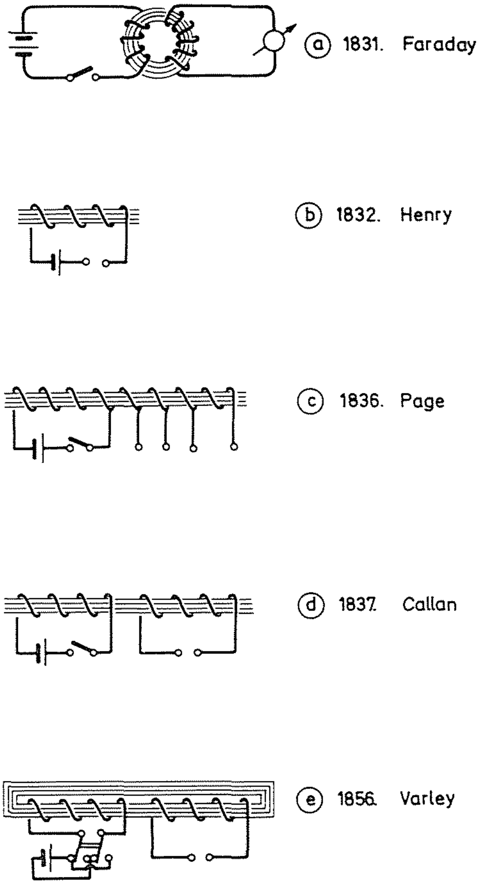

Fig. 1. D. C. antecedents

application of a closed core for the purpose of telephony (British Patent, 1856) (Fig. 1e).

With the exception of Faraday's and Varley's induction coils, all the above devices had open cores. This arrangement indeed led to greater sparks, due to the greater electromagnetic energy accumulated in the device.

At that time, alternating current was still unknown, and hence the described experiments are only precursors of the transformer.

In the years when alternating current became known, many experts were involved in the problem of the "subdivision of electric light", that is, how could the intensity of a single arc lamp fed by a single generator be distributed over several lamps of lower intensity in the same circuit. The problem would today be formulated as the question how to feed several arc lamps from a single alternator.

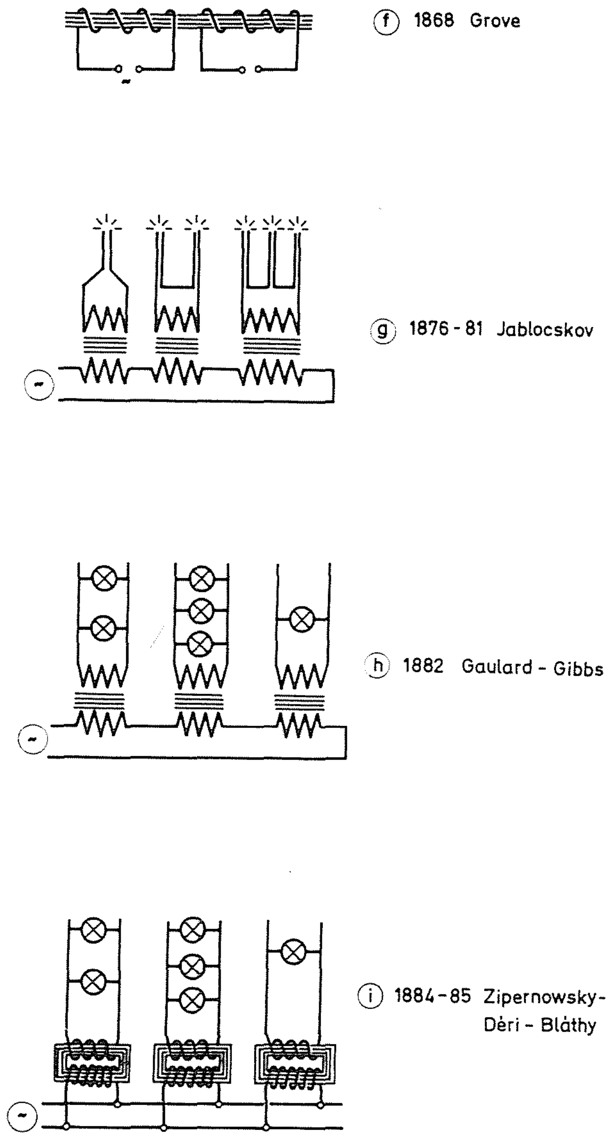

Fig. 2. A. C. antecedents

After 1857, following the first steps made by the French company Alliance, the manufacture of alternating current generators was taken up in many countries. It is a curious fact that even later, engineers and scientists engaged in power research failed to take notice of Varley's suggestion and continued to experiment with open-core solenoids.

W. R. Grove was the first to apply, in 1868, alternating current to one of the windings of an open-core inductor (Fig. 2f).

The first significant step towards solving the problem was made by P. N. Jablochkov, a retired Russian military engineer. In his lamp two carbon rods were placed side by side, separated by insulating material. These "candles" were fed with alternating current through open-core induction coils connected in-series on the primary side. The lamp was exhibited in 1876—81 in several European countries (Fig. 2g).

In 1879, Edison succeeded in solving the problem of economic electric illumination, using incandescent lamps and direct current. However, economic transmission and distribution of electricity at great distances was yet unsolved.

Among many experiments, patents and concepts developed by de Meritens, C. T. Bright, E. Edwards, A. Normandy, J. B. Fuller, R. Kennedy, Deprez, Carpentier and W. Siemens, only one attempt was put to practical use (Fig. 2h).

L. Gaulard and E. D. Gibbs applied, in 1882, for a British patent covering a new current distribution system by inductors termed "secondary generators". The primary windings of these devices with a ratio of 1 : 1 were connected in series. The inventors presented the system first in 1883 at a small electrical exhibition in the Westminster Aquarium in London. Their apparatus had an open iron core and the voltage was controlled by pushing in and pulling out the iron core into and from the coil, resp.

The Gaulard-Gibbs system was subsequently exhibited at the Turin Fair in 1884. It happened that a young Hungarian engineer, Otto T. Bláthy from the Electrical Department of the Ganz Works in Budapest was present at the fair, since Ganz was also among the exhibitors. (It exhibited an a. c. current illumination system consisting of 500 incandescent lamps. L. Kossuth, the former leader of the Hungarian War of Liberty in 1848—49, living in exile in Turin, also visited the fair.) Bláthy was interested in the Gaulard-Gibbs system, but had a keen eye for its weaknesses, namely the difficulties in voltage control inherent in in-series connection as well as the unfavourable magnetic conditions resulting from the open core. In the installation, the load current varying in magnitude circulated through all primary coils. In addition, the leakage reactance and the magnetizing current of the apparatus was high by reason of the open iron core. Due to these conditions, consumer voltage varied between wide limits depending on actual load.

Returning from the fair Bláthy reported his experiences to the head of Ganz's Electrical Department K. Zipernowsky, who was permanently experimenting in company of M. Déri. Bláthy's report gave new impetus to the research in progress at Ganz on the subject of the "subdivision of electric light".

It is the historical merit of the Ganz Works, a pioneer in alternating current technique, and of its three engineers Zipernowsky, Déri and Bláthy that

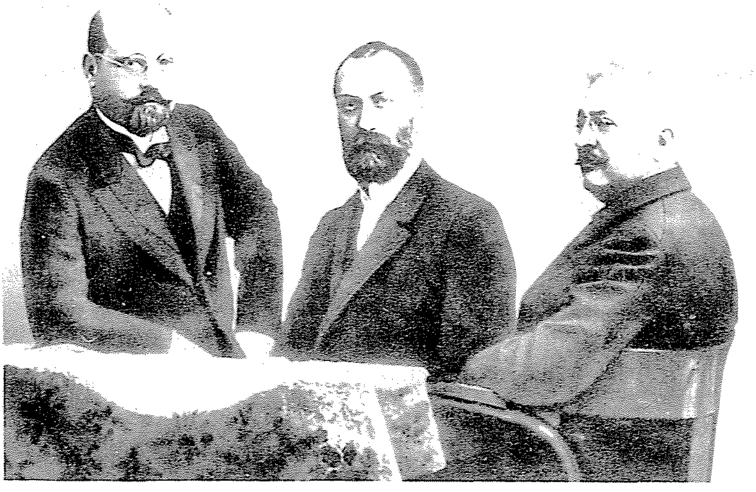

Fig. 3. K. Zipernowsky, M. Déri, O. T. Bláthy

rapid development of electrical engineering became possible through the realization of the transformer system in 1884—85 (Fig. 3).

The new system, bringing world fame to the Ganz Works, was based on induction apparatuses termed by the inventors "transformers". The characteristic features distinguishing them from earlier induction apparatuses were closed iron cores, transformation ratios chosen freely, and both circuits

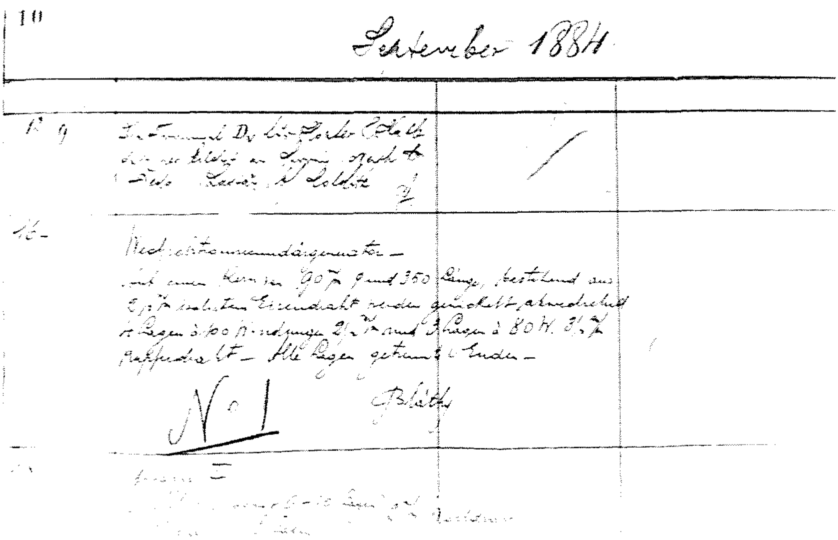

Fig. 4. Data of the transformer No. 1

connected in-parallel, to transform primary high voltage into low consumer voltage.

The earliest records available at Ganz dealing with their experiments on the transformer problem are dated July 17 and August 7, 1884. According to these records and to the transformer register-book of Ganz, the transformer No. 1 was delivered on September 16, 1884. It was, however, not a true transformer in the above sense, because it had an open core. Its data were as follows: 1400 W, 40 Hz, 120/72 V, 11.6/19.4 A. Its 350 mm long, 90 mm diameter open core was made of 2.5 mm diam. insulated iron wire. Four of these early apparatuses with open cores and termed by Ganz "secondary generators" were completed in the year 1884; No. 3 was delivered to a flour mill in Budapest, and No. 4 was made to the order of a customer in Sevastopol, Russia (Fig. 4).

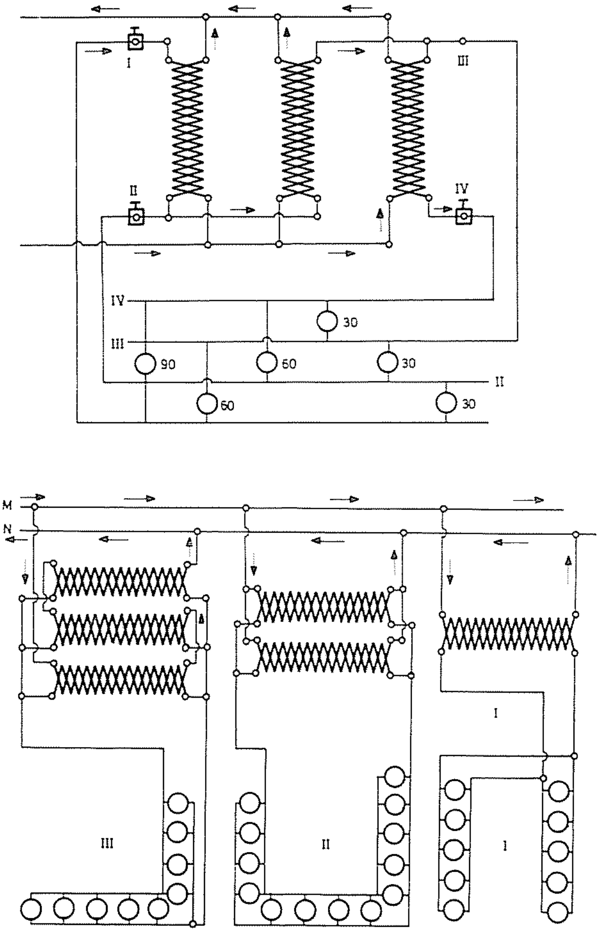

Fig. 5. Patent sketch for in-parallel operation

The first patent applications were filed on January 2, March 3 (Austria—Hungary), February 18 and March 6, 1885 (Germany). The first two covered in-parallel connection and transformer ratios chosen freely, the others the two basic forms of transformers with closed cores built up from insulated steel wire and steel plate, resp., namely the core-type and the shell-type transformer (Fig. 5, Fig. 6).

The 6000 W transformers No. 6 and No. 7 were made early in 1885 for the "Vienna experiment": M. Déri presented the Ganz transformer system in the Technologisches Gewerbemuseum in Vienna.

The first transformers made beyond question with closed cores were No. 8 and No. 9. They were made for the Patent Office to serve as illustrations for the patent applications mentioned above. Both were shell-type transformers;

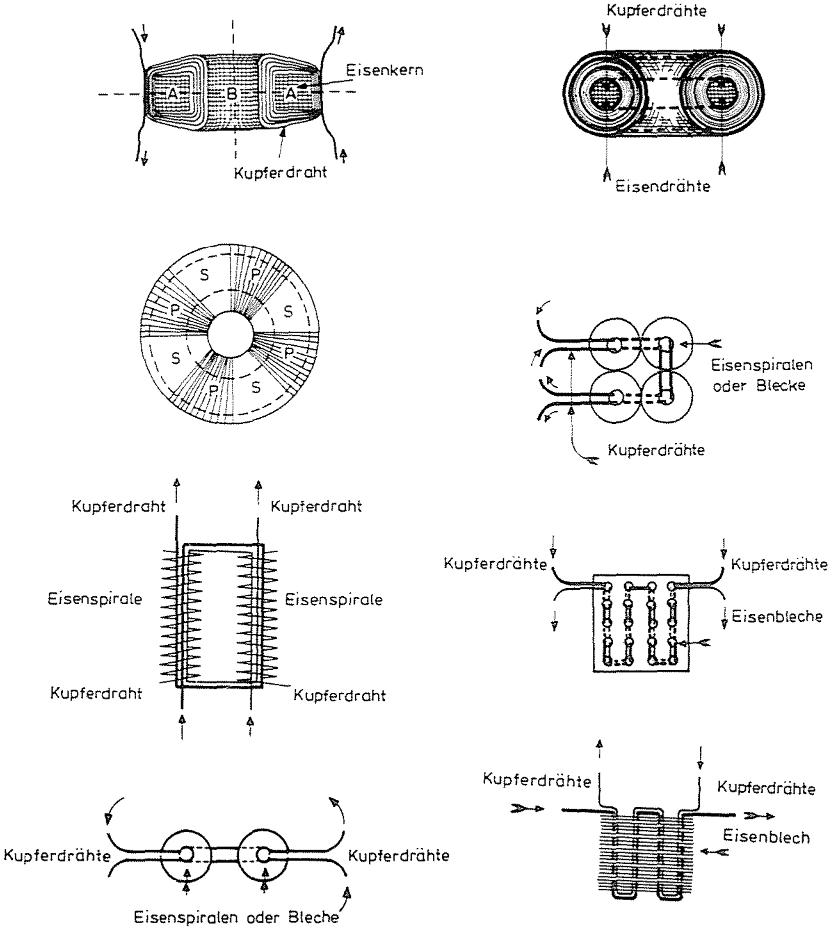

Fig. 6. Patent sketch for closed-core transformers

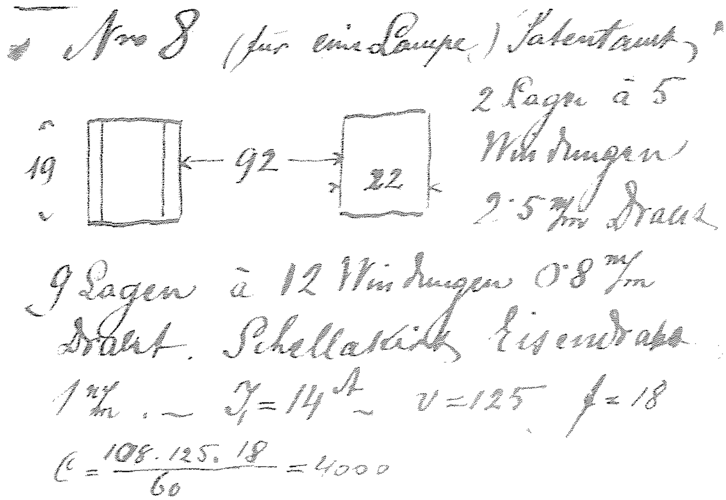

Fig. 7. Data of the first closed-core transformer

one had an iron core made of insulated wire, the other's core was a structure made of 0.5 mm sheet (Fig. 7).

The question what part one or the other of the three prominent Hungarian engineers had played in the invention of the transformer has frequently been posed. In all probability, in-parallel connection was Zipernowsky's idea, which he developed in co-operation with Déri, while the closed core was proposed by Bláthy who appears to have recognized the practical importance of the magnetic Ohm's law very early. This is evidenced by the names of the patent owners and by the titles and contents of the Ganz booklets from the years 1885—87. For instance, the system was first named "System Zipernowsky—Déri" and later "System Zipernowsky—Déri—Bláthy". The three inventors made an agreement in September 1885 concerning their respective participation in the incomes of the inventions, according to which the shares of Zipernowsky and Déri were 40% each, and Bláthy's share was 20%; in November 1889 this proportion was modified to 35—35—30%. It is an unquestionable fact that at the Budapest Exhibition in May 1885 the transformer system was already fully developed and that it was the joint product of the three brilliant inventors.

The Ganz Works presented the transformers to the public at this exhibition. Over 1000 carbon filament lamps (Edison make) illuminated the exhibition; they were supplied through several shell-type transformers. The system was fed by a Ganz-made single-phase synchronous generator. The terminal voltage of the machine was 1350 V, it supplied an alternating current of 70 Hz. In the summer of 1885, a second part of the exhibition was opened; it was illuminated through four core-type transformers supplied with an alternating current of 42 Hz. The whole installation operated satisfactorily until the closure of the exhibition in November 1885.

The novel devices termed "transformers" by the inventors marked a great step forward in electric power distribution. By virtue of in-parallel connection, terminal voltage became largely independent of load. The introduction of closed cores reduced the magnetizing current to an acceptable value, and efficiency was greatly improved.

Core-type transformers were also termed ring transformers. The first was No. 28, delivered on May 15, 1885.

Still in this same year the transformer system was exhibited at industrial fairs in London and Antwerpen with great success.

The transformer No. 16 was given as a present by the Ganz Works in 1937 to the Edison Institute (Henry Ford Museum) at Dearborn near Detroit, Mich (Fig. 8). Two other old transformers are exhibited in the Historical Museum of Budapest (Figs 9 and 10).

The scientific significance of the Ganz transformer system was first acknowledged by Galileo Ferraris, an important Italian physicist. In a lecture held in July 1885 he stated that solution of the long-standing problem of power transmission had finally been solved by Zipernowsky, Déri and Bláthy.

The inventors applied for patents covering their system in every industrial country of importance. Leading technical journals described the transformer all over the world. The Electrical Review, London, in its issue of August 8, 1885, gave an enthusiastic account of the success achieved by Ganz.

Following the above exhibitions orders poured to the Ganz Works, and the transformer No. 86 was completed in the very year 1885. The hundredth transformer was delivered on March 18, 1886, the thousandth in 1889 and the ten thousandth in 1899.

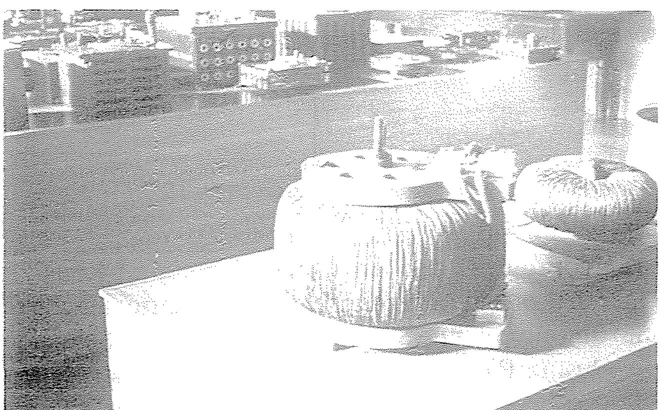

Fig. 8. Transformer No. 16

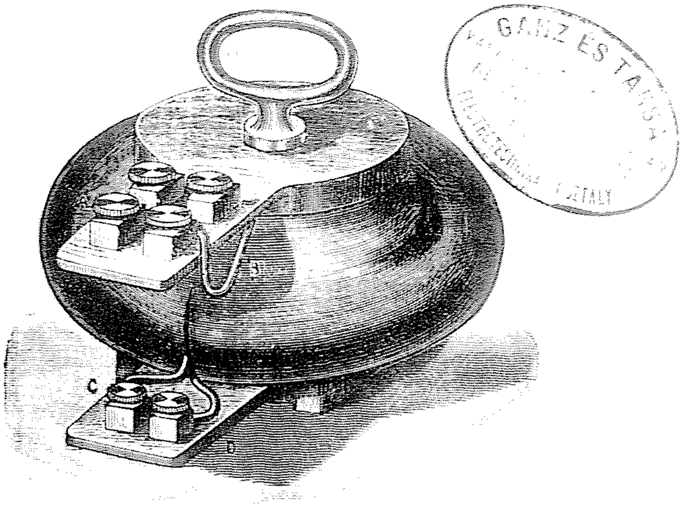

Fig. 9. Shell-type transformer, 1885

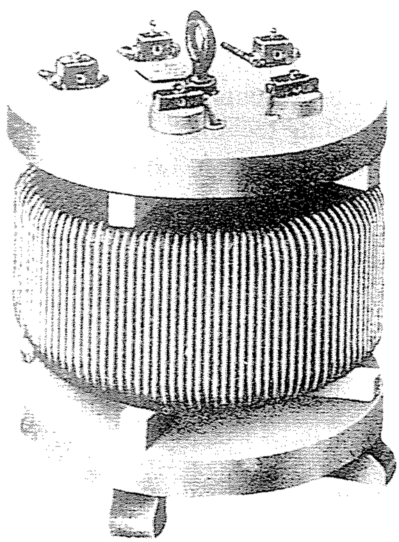

Fig. 10. Core-type transformer, 1885

Ganz's rapid progress and onrush of success obviously aroused the interest of other European manufacturers of electric machinery in transformers. Some among them (Schwartzkopf, Helios, Schneider—Creuzot, Planas Flaquer, Franz Pichler and Co.) acquired the license from Ganz for their manufacture; others, however, chose to exploit the fact that the wording of the Ganz patents was unfortunately not quite unequivocal. The ensuing patent infringement suits had an unfavourable outcome for the Hungarian inventors in Great Britain and in Germany.

The chief electrician of Edison Central Station, Pearl Street, New York City, J. W. Lieb visited the Ganz Works in 1885 and was filled with enthusiasm; he urged the Edison Electric Light Company to buy the patent rights to manufacture the Ganz transformers in the United States, but the company, at that time, did not realize the commercial importance of the invention. Only one year later, in 1886, was an agreement arrived at for an option concerning the manufacture for twenty thousand dollars. No use, however, was made of the option; therefore Ganz sued the Edison Company in 1890 to be released from the agreement on the claim that Edison had not fulfilled its obligation.

George Westinghouse took a different view on the importance of transformers. It was Pantaleoni who emphatically advised Westinghouse to take up work in alternating current. The Gaulard-Gibbs patents were therefore bought, and the first "secondary generators" in the U. S. arrived in November 1885; they were, however, fitted with closed magnetic circuits already. Westinghouse charged W. Stanley with the introduction of "secondary generators" in the United States.

While the Ganz transformer system was first reported in the U. S. in the October 3, 1885 issue of the Electrical Review, New York, Stanley's patent applications followed on October 23, and November 23, 1885. The first alternating current system in the U. S. applying transformers was put into operation at Great Barrington, Mass., on March 20, 1886, in the very days when Ganz completed its 100th transformer.

Zipernowsky, Déri and Bláthy were unquestionably the first to find the only practical solution for electric power transmission, at the very moment when — considering the status of technical development of the time — the imperative need to solve the problem arose. Their outstanding achievement won the famous international race.

The Ganz Works retained its leading role in the manufacture of transformers for a considerable period, and remained the world's most important manufacturer of transformers.

Power station building activities gathered momentum at the Ganz Works by the development of the transformer system, although previous to this development Ganz had already delivered more than 150 a. c. power plants and illumination installations.

The first Swiss order for a transformer-fed illumination installation was given to Ganz in September 1885. Two self-excited single-phase generators were furnished for a small hydro-electric power station utilizing the energy of a water-fall near Littau (at a distance of some kilometres from Luzern). Current was carried to consumers (mills, villages, hotels in Luzern etc.) through a 1800 V transmission line, and many thousand incandescent lamps were supplied with 30 V voltage by shell-type transformers. Voltage was regulated automatically by small current transformers ("compensators") also in use in subsequent Ganz power stations, and by Bláthy's mercury regulator. The small power station's output was later increased and the station was enlarged.

The Ganz Works attained a substantial positional advantage by its new power distribution system. In addition to generators and transformers, the manufacture of auxiliary machines, regulating and testing equipment, switches etc. was started, all of them designed at Ganz; they largely contributed to safe operation of power stations. Between 1885 and 1890, Ganz delivered close to 60 and till the turn of the century a total of 300 complete power stations to countries all over the world, fitted first with single-phase and later with three-phase (in rare cases with two-phase) systems. In the beginning the stations served for illumination, later for general power transmission. In addition, Ganz licensees were important manufacturers: for instance Planas Flaquer alone commissioned around 120 Ganz-system plants on the Iberian peninsula till 1900.

The first truly metropolitan-size steam power station was installed by Ganz in the Cerchi district of Rome in 1886. It had six steam engines fed by 14 furnaces. Two smaller engines had an output of 150 HP, the four large ones had an output of 600 HP each. The 2000 V single-phase current of the Ganz-made synchronous generators directly coupled to the steam engines was transmitted by underground cables to the city transformer stations, where the voltage was transformed to 150 V.

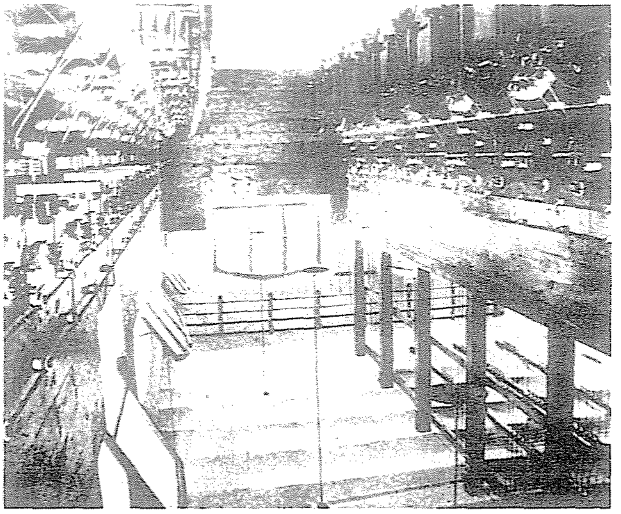

Fig. 11. Porta Pia substation in Rome

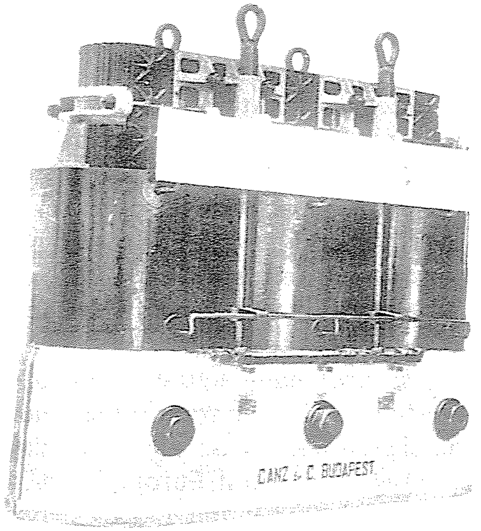

Fig. 12. Three-phase transformer

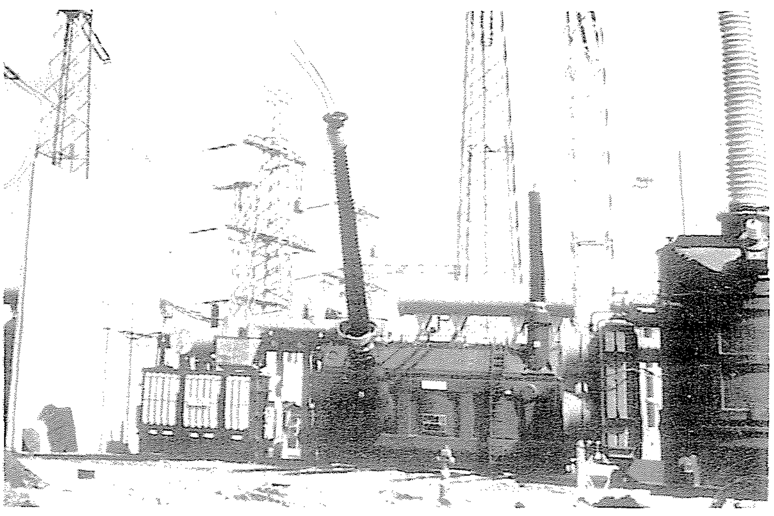

Fig. 13. 750 kV transformer

After the Cerchi power station, Ganz Works delivered, for decades, all electrical equipment to the city of Rome, including, in 1892, the largest hydroelectric power station of that time in Europe. It was installed at Tivoli near Rome with a total output of 2100 HP. At the city end of the Tivoli-Rome transmission line, in the Porta Pia substation, 32 transformers of 30 kVA each were installed, at the time considered very large (Fig. 11). The town of Tivoli also had street lighting; before the Ganz system was introduced, in-series secondary generators of the Gaulard-Gibbs type operated it.

The bridge between the early period of transformers and our own age is represented by the introduction of the three-phase system. The first three-phase transformers of the Ganz Works were designed by K. Kandó after having joined the factory in 1893.

Column-type transformer cores were developed in the Ganz Works in the last decade of the 19th century; the structure appeared particularly suitable for three-phase applications. It was used in the 10 000th transformer manufactured at Ganz in 1899, and equally in the transformers shipped for the Tellina Railway (Italy) after the turn of the century.

The 100 000th transformer manufactured by Ganz was delivered in 1961.

The peak achievement of Ganz in transformer manufacture was the 750 kV-type in 1978. The eight single-phase units manufactured were the first transformers of this voltage in Central Europe, with 367 MVA output per phase and serving to connect 400 kV and 750 kV networks (Fig. 13).

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