Galileo Ferraris: A Life Dedicated to the Electrical Sciences

M. Mitolo (°), M. Tartaglia(*)

(°) ESI, Foothill Ranch, CA, USA

(*) Politecnico di Torino (Italy), Dipartimento Energia

This article illustrates the life and work of Prof. Galileo Ferraris (1847-1897), an Italian engineer and scientist who dedicated his life to the study of electricity and its applications in the 19th century. His contributions to different engineering disciplines were remarkable, as were his efforts to develop and disseminate electrical knowledge. In this article, we will briefly discuss his publications and formidable laboratory experiences from 1870 to 1897. All the original works of Galileo Ferraris, his numerous papers and books, are available for free download from the digital repository of the central library of the Politecnico di Torino, the university that he contributed in creating.

His life

Galileo Ferraris was born on 30 October 1847 in Livorno Piemonte (Kingdom of Sardinia). At the age of 22, he obtained the master's degree in Civil Engineering, and decided to pursue an academic career. He became an assistant professor under the supervision of Prof. Codazza, within the Technical Physics Department of the Royal Industrial Museum of Turin, Italy. In 1877 he succeeded Prof. Codazza as a full professor of technical physics. Ferraris attended the International Conference in Paris, in 1882, as a delegate of the Italian Government. He was the vice-chair of the International Exposition in Vienna in 1883, and in 1884 he hosted the International Electrical Exhibition in Turin, Italy. During this event, he was also the chair of the award committee, which granted a prize to Gaulard and Gibbs for the invention of the transformer. In 1888, Prof. Ferraris founded the School of Electrotechnics with educational electrical laboratories (later on incorporated into the Politecnico di Torino), the first institution of its kind in Italy, and most likely in the world (Figure. 1) [1].

Postprint of the paper with the same title published on
IEEE Industry Applications Magazine, Sept.|Oct. 2016, pp. 8-11.
https://m.ieee.org/publications_standards/publications/rights/ieeecopyrightform.pdf

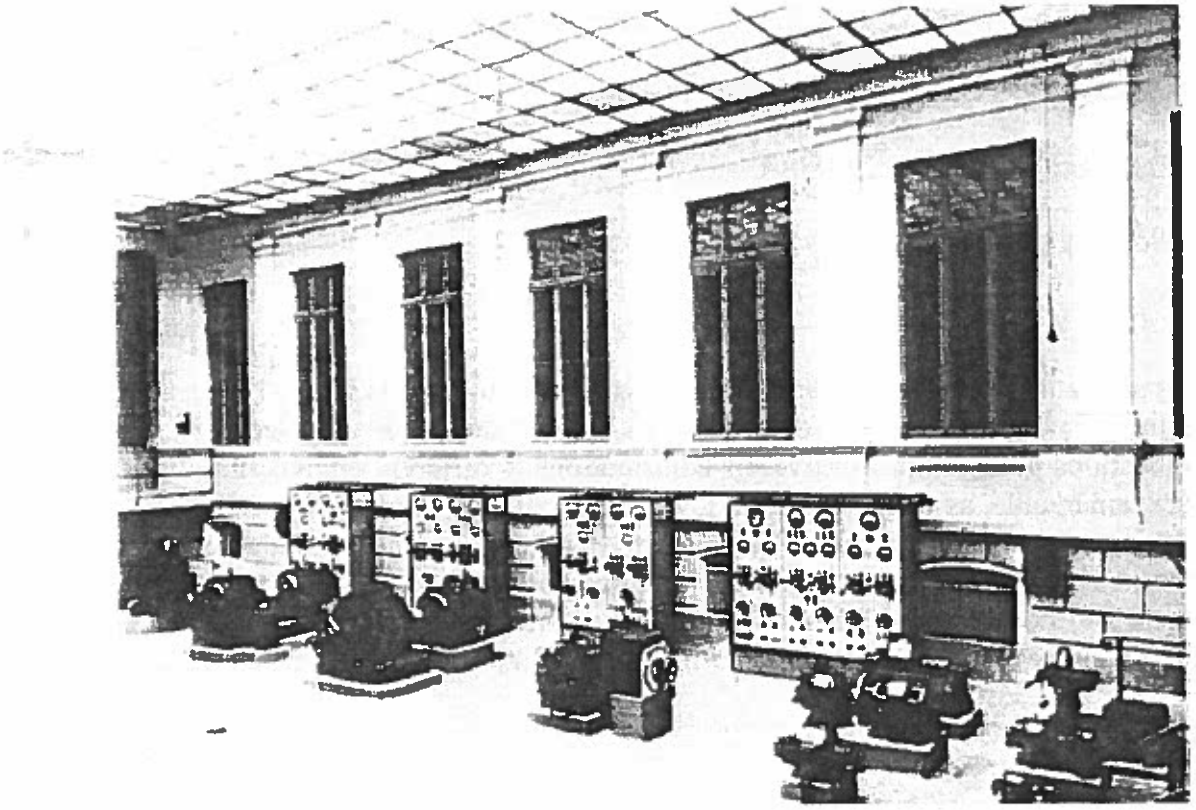

Figure 1 The Electric Machines laboratory at the School of Electrotechnics

(Photo courtesy of the Central Library of the Politecnico di Torino; www.polito.it)

Prof. Ferraris was a pioneer in the development the ac distribution system and the induction motor. He extensively published the experimental results of his work on crucial aspects of electrical engineering, which forever influenced the way we produce and transport electric energy today. In 1989 Galileo Ferraris (Turin), Erasmus Kittler (Darmstadt), William H. Lindley (Frankfurt), Friedrich Uppenborn (Berlin), Heinrich Friedrich Weber (Zürich) were asked by the authorities of Frankfurt to solve the problem of the city's electrical distribution system.

Prof. Ferraris was recognized, in 1891, at the Frankfurt Electrotechnical Exposition for his research on magnetic fields, where an electric system, including a 175 km transmission line represented a major accomplishment for electrical applications.

Prof. Ferraris was the Italian delegate to the Chicago International Conference on Electricity in 1893, where his influence garnered group-member consensus on the definitions of the units of measurement: joule, watt and henry. In 1896, he represented Italy at the Geneva Conference, where he lectured on new and existing units of measurement. In the same year, he established the Italian Electrical Association (AEI), which continues his work, and now includes electronic and telecommunications disciplines as the Italian Electrical, Electronics, Automation and Telecommunication Association. In 1896 he was also appointed senator of the Italian Kingdom. Prof. Ferraris also served as a city alderman from 1887 to 1897 in Torino. From 1895 to 1897 he was a counselor in his home-town of Livorno Piemonte.

Despite his poor health, prof. Ferraris kept teaching, but on 1 February 1897, he had to stop his lecture. It is reported that he told his students: "Gentlemen, the machine is broken, I cannot continue my lecture". One week later he died of pleural pneumonia.

His research activity

The impetuous urge to further develop electrical applications, the national and international initiatives and proposals promoted by expositions and conferences and autonomous ideas gave rise to an intense research activity. The scientific contribution of Ferraris sparked progress in the field of electrical applications, and today, even a century later, many advancements influenced by his work are still shared and discussed at national and international conferences. He is absolutely worth studying. The original Ferraris papers were written in Italian. They were collected and reprinted by AEI in 1902 [6], in 1903 [7] and in 1904 [8]. In order to attempt to summarize the most significant topics of his scientific research, a detailed list of the subjects that he treated is herein condensed:

- analysis of currents in conductors [12], [16]
- electric behavior of the telephone [13]-[15]
- electric and photometric measures [11], [22], [28]
- transformers behavior and models [17]-[20], [29]
- induction motor [21], [25]
- synchronous motor [23]
- ac electrical distribution [26], [27], [32], [39]
- electric lighting [26]-[28], [32], [39]
- electromagnetic fields [24]
- optics [35]-[37]

- mechanics [34], [38].

In [3] a useful synthesis of Ferraris production is given (in English) in the book [3] which was prepared on the occasion of the centenary of his death.

Conferences reviews were given in [26]-[28], [30] and [31].

Ferraris' work focused on a machine that he defined as a "*secondary generator*", now universally known as a transformer, which was firstly introduced by Gaulard and Gibbs. The transformer had an open iron core, and he studied its behavior, and functionality and established the electrical calculation methodology under ac conditions. He understood and measured eddy and hysteresis currents, as well as the transformer efficiency. This work allowed him to better understand the improvements obtained by Zipernowsky, Déri and Blathy, who introduced the closed iron core transformer.

As the result of his experiments started in 1885, in 1888 prof. Ferraris presented the prototype of the induction machine with a horizontal axis, which he jokingly named the "grille" (Figures 2 and 3) to the Royal Academy of Sciences in Turin, Italy.

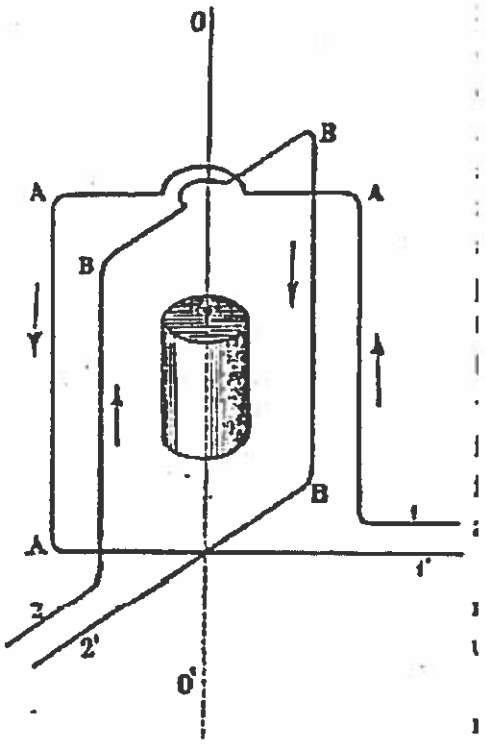

Fig. 2 Basic idea of a rotating field and the two-phase rotating machine

(Photo courtesy of the Central Library of the Politecnico di Torino; www.polito.it)

The basic idea of the *magnetic revolving field* came to him from the polarization of light waves; he firstly conceived a two-phase induction motor.

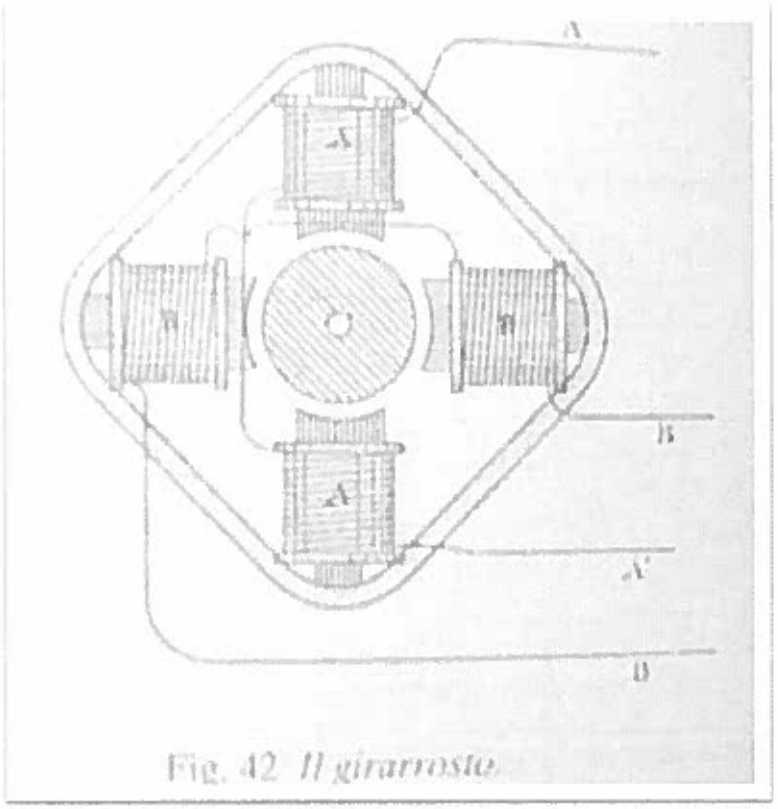

Figure 3 First schematic of the induction machine

(Photo courtesy of the Central Library of the Politecnico di Torino; www.polito.it)

In a preliminary experiment on 1885, the revolving-field was generated by two stationary coils, installed perpendicular to each other, through which two currents of the same frequency circulated but were displaced by a phase angle of 90°. A copper cylinder immersed in the revolving field was consequently moved to produce mechanical work, due to the interactions between the resulting electromagnetic forces and induced currents. In 1888 three years after the first experiments, the inventor published the paper [21] where he formally demonstrated the basic principles of the machine's behavior.

Postprint of the paper with the same title published on
IEEE Industry Appl ications Magazine, Sept.|Oct. 2016, pp. 8-11.

The invention of the induction machine and the use of transformers became the fundamental pillars of the ac-electrical revolution. The experiments performed on the occasion of the Torino exposition confirmed the importance of electric energy due to the relative simplicity of its transport and regulation, which were the basis for following technological developments. A visionary and coherent description of an electric power system is found in [39]. In this paper a new application of an asynchronous machine was proposed for the so called *phase rotation transformer* (Fig. 4).

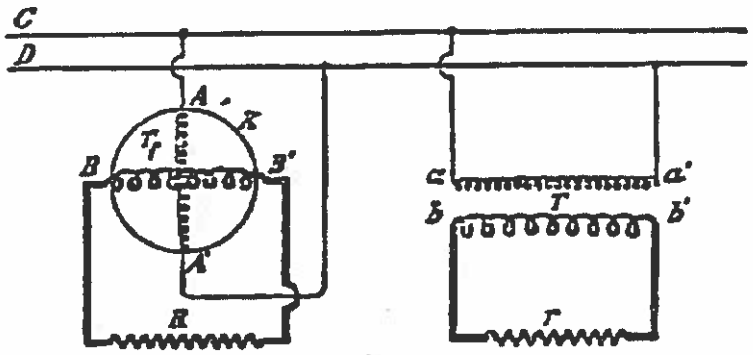

Figure 4 An induction machine used as a phase-rotation transformer [39]

(Photo courtesy of the Central Library of the Politecnico di Torino; www.polito.it).

In Fig. 4, two electric machines are used to generate a two-phase ac system: an ordinary transformer T and a phase-rotation transformer T_f. The use of asynchronous machine to obtain voltages with different phases became popular in electric laboratories, and Ferraris' idea consisted [39] of the use of a rotor to generate a revolving field in the BB' winding (Fig. 4), instead of the usual application of a rotor winding installed according to the wanted phase rotation.

His publications

In our opinion, the use of the Italian language was, and is, a limiting factor for the dissemination of Ferraris' scientific production. For this reason, in this article all the titles of his publications have been translated in English. The Central Library of the Politecnico di Torino provides access to all his original work (http://digit.biblio.polito.it/view/percorsi/GFERRARIS.html). The chance to read the complete mathematical formulations included in Ferraris' work, may allow today's IEEE

Postprint of the paper with the same title published on
IEEE Industry Appl ications Magazine, Sept.|Oct. 2016, pp. 8-11.

Industry Applications Society members, and electrical engineers at large to better understand his monumental work.

References

Selection of Journal Papers, Conference Proceedings and Books.

[1] G. M. Pugno, "*Storia del Politecnico di Torino: dalle origini alla vigilia della seconda guerra mondiale*", 1959; digitalization of 2011.

[2] R. Manigrasso, A.P. Morando, "La nascita dell'Ingegneria Elettrica", pages 1-234, Tecniche Nuove, Milano, 1997, ISBN 88-481-0361-8.

[3] "Galileo Ferraris and the Conversion of Energy Developments of Electrical Engineering over a Century", Proceedings of the International Symposium, Torino 27-29 October 1997, pp. 1-526. ISBN 88-900352-0-X.

[4] R. Felici, A. Battelli, V. Volterra, "In memoria di Galileo Ferraris", published on the Italian Physics Journal Il Nuovo Cimento, serie IV, Tomo V, January 1897.

[5] R. Grossi, "L'archivio di Galileo Ferraris", published on the Journal Rassegna degli Archivi di Stato, nuova serie – anno I , no. 1-2, January-August 2005, pp. 1-169.

[6] 'Opere di Galileo Ferraris. Volume I', Ulrico Hoepli Editore-Libraio della Real Casa, Milano. Pubblicate per cura dell'AEI (Associazione Elettrotecnica Italiana) 1902, pp.1-492 .

[7] 'Opere di Galileo Ferraris. Volume II', Ulrico Hoepli Editore-Libraio della Real Casa, Milano. Pubblicate per cura dell'AEI (Associazione Elettrotecnica Italiana) 1903 pp.1-473.

[8] 'Opere di Galileo Ferraris. Volume III', Ulrico Hoepli Editore-Libraio della Real Casa, Milano. Pubblicate per cura dell'AEI (Associazione Elettrotecnica Italiana) 1904 pp.1-367.

[9] V. Cantoni, A. Silvestri, 'Storia della Tecnica Elettrica', pp. 1-451, Cisalpino Istituto Editoriale Universitario Monduzzi Editore, Milano, 2009.

[10] R. Gobbo,' L'archivio di Galileo Ferraris' , Rassegna degli Archivi di Stato, Nuova Serie, anno I – n. 1-2, pp.1-170.

English Translation of the Table of Contents of Volume [6]

[11] G. Ferraris, 'On the Use of Ordinary Compass to Measure Electric Currents' in [6], pp.13-76, published in 1871.

[12] G. Ferraris, 'Mathematical Theory of Electricity Propagation in Solid Homogeneous Bodies", in [6], pp.13-76. published in 1872.

[13] G. Ferraris, 'On a Demonstration of the Helmotz Principle on the sound tempra obtained by Experimental Results on a Telephone', in [6], pp.81-90, published in 1877-78.

[14] G. Ferraris, 'On the Graham Bell Telephone', in [6], pp.91-112, . published in 1877.

[15] G. Ferraris, 'On the Intensity of Electrical Currents and of Extra-Currents in a Telephone ', in [6], pp.113-148, published in 1977-78.

[16] G. Ferraris, 'Theorems on the Distribution of Direct Electric Currents', in [6], pp.149-162, published in 1879.

[17] G. Ferraris, 'Theoretical and Experimental Research on the Secondary Generator 1 by Gaulard and Gibbs ', in [6], pp. 163-254, published in 1886.

[18] G. Ferraris, 'On the method proposed by Hopkinson to determine the efficiency of the Secondary Generator by Gaulard and Gibbs', in [6], pp.255-260. published in 1886, published in 1884-85.

[19] G. Ferraris, "On the Phase Shifts of Currents, of Magnetic Induction and on the Losses in Transformers", in [6], pp.261-324, published in 1888.

[20] G. Ferraris, "Results of Some Experiences on Zipernowsky, Déri, Blàthy Transformer", in [6], pp.325-332 published in 1886.

[21] G. Ferraris, "Electrodynamic Rotation by means of Alternating Currents", in [6], pp.333-348, published in 1888.

[22] G. Ferraris, "On the Method to Electrodynamometers to Measure Hysteresis and Eddy Current Losses in a Transformer", in [6], pp.349-354 published in 1892.

[23] G. Ferraris, "Syncronous AC Electric Motor", in [6], pp.385-390, published in 1894.

[24] G. Ferraris, "Geometric Theory of Vector Fields to Introduce Electrical and Magnetic Phenomena", in [6], pp.391-492, published in 1897.

English Translation of the Table of Contents of Volume [7]

[25] G. Ferraris,'New Induction Machines", in [7], pp.1-16.

[26] G. Ferraris,'Public Conferences on Electric Lighting", in [7], pp.17-116.

- 26.1 On Energy Equivalence and Conservation.
- 26.2 On the Electric Current.
- 26.3 On Induction Machines.
- 26.4 On the Lighting via Electric Arc.
- 26.5 New Electric Lamps.

1 The Secondary Generator was the first name attributed to Transformers.

[27] G. Ferraris, 'On Industrial Applications of Electric Current at the International Exhibition on Electricity in Paris 1881', in [7], pp.117-271.
- 27.1 Generation, Storage and Distribution of Electric Energy.
- 27.2 Applications of Electric Energy (Mechanical Work Distance Transmission, Electric Lighting, Electro-metallurgy).

[28] G. Ferraris, 'On the Results of the First Session of the International Conference on Electricity', in [7], pp.271-317.
- 28.1 Determination of ohm.
- 28.2 Ground Electric Currents, Lightning and Lightning Conductors. Telegraph Connections among metereologic Observatory.
- 28.3 Choice of the Measuring Unit of Light Intensity and Analysis of Photometric Methods.
- 28.4 Conclusions and proposals.

[29] G. Ferraris, 'Relation of the International Commission for a Special Price (£ 15,000) from the Italian Government and Torino Municipality ', in [7], pp.317-336.

[30] G. Ferraris, 'Electrotechnics at the Universal Exposition of Paris in 1889', in [7], pp. 337-419.

[31] G. Ferraris, 'On the International Conference on Electricity of Chicago, 1893', in [7], pp. 419-445.

[32] G. Ferraris, 'On the Transmission of Electric Energy', in [7], pp.445-470.

[33] G. Ferraris, ' Obituary of Luciano Gaulard', in [7], pp.471-473.

English Translation of the Table of Contents of Volume [8]

[34] G. Ferraris, 'On Telodynamic Hirn Transmissions', in [8], pp.1-72

[35] G. Ferraris, ' Cardinal Properties of Dioptric Instruments', in [8], pp.73-263.

[36] G. Ferraris, 'On Telescopes with Many Lens at Suitable Distances', in [8], pp.263-288.

[37] G. Ferraris, 'On Dioptric Convergent and Divergent Systems', in [8], pp. 289-292, in German.

[38] G. Ferraris, 'On a Measuring Method of Water Transported by Steam', in [8], pp. 293-314.

[39] R. Arnò, G. Ferraris, 'A New System for Electric Energy Distribution Using Alternated Currents', in [8] , pp. 315-330.

[40] G. Ferraris, 'Speech for the Unveiling the monument dedicated to Felice Chiò', in [8], pp. 331-352.

[41] G. Ferraris, 'In memory of Giuseppe Basso', in [8], pp. 353-364.

[42] Bibliography , in [8], pp. 365-367.