The Giovi line and the three-phase electrification

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***Abstract* — The three-phase railway electrification was largely developed in Italy early in 20th century and became known as the "Italian system" for railway electrification. It proved a suitable system, in particular, for railways facing high slopes. The first experiment, carried out for the Valtellina line in 1902, was followed in 1911-1913 by that of the Giovi line connecting the Mediterranean sea (Genoa) to the Po valley and the continental Europe. In the following three decades in Italy over 1800 kms where electrified at 3400 V 16.7 Hz. The paper describes the origin and the characteristics of the Giovi line.**

***Index Terms* — Electric railways, three-phase electrification, history of technology.**

I. INTRODUCTION

Italy is a mountainous country with abundant water power but negligible fossil fuels. Its first railways were steam powered, but electric traction, when it became possible, was a very attractive option.

Various systems of electrification, some using alternating current and some direct current, were tried out on different lines. A three-phase alternating current system with two overhead wires and induction motors on the trains was used from 1902 on the Valtellina line which ran north from Lake Como into the Alps [1]. It proved very successful and the system was chosen for the very busy line running from the port of Genoa through the Giovi pass into Italy's industrial heartland around Turin and Milan. Known as the 'Italian System' of railway electrification, it became the national standard for many years until superseded by the direct-current system used in other European countries.

II. THE GIOVI LINE

At the beginning of the twentieth century the railway running north from the port of Genoa was the most heavily loaded line in Italy, linking the port with Turin and Milan. Near Genoa the line had to cross the Appenines, with gradients up to 3.5%, and went through the Giovi tunnel which, at 3,258 metres, at the opening in 1854 was the longest railway tunnel in the world. [2]

The oldest part of the line, from Genoa to Turin in what was then the Kingdom of Piemonte, was built between 1845 and 1854.

The line from Milan was completed in 1867, joining the Turin - Genoa line at Arquata Scrivia (Fig.1). Coal brought by sea from Wales and imported at Genoa was both the fuel for the steam-powered trains and a significant part of the freight conveyed on the railway.

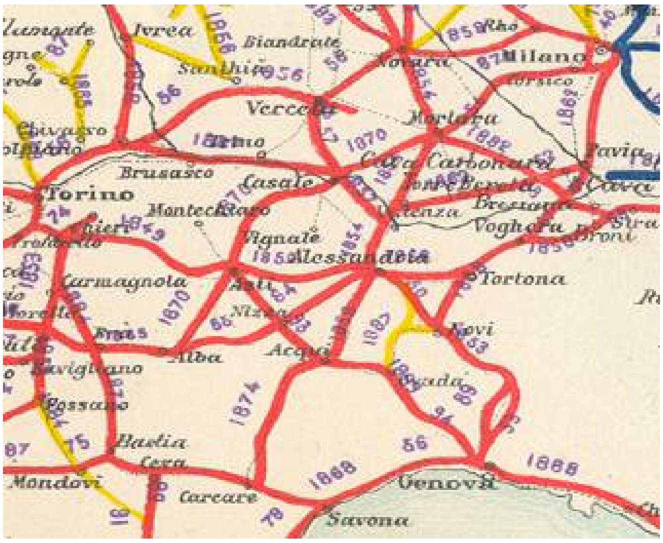

Figure 1. Map of Italian railways in the north of Italy: end of 19th century.

After the unification of Italy in 1861 the railway tracks were owned by the state but, from 1885 until 1905, trains were operated by three separate companies: the Rete Mediterranea, which ran the Giovi Line, the Rete Adriatica, and the Rete Sicula. [3, 4]

The port of Genoa, and consequently the Giovi line, was of increasing importance after the opening of the Suez Canal in 1869 and the building of tunnels through the Alps at Gothard in 1882 and at Simplon in 1906. To increase the capacity of the railway a second line between Genoa and Arquata, the 'succursale del Giovi', was opened in 1889, following a slightly different route [5]. The 'old' Giovi line passed through Pontedecimo, while the succursale went via Mignagnego; the latter included a 8.3 kilometer long tunnel with a slope of up to 2.6%. (Fig.2)

Figure 2. Map of the two Giovi lines.

On 11 August 1898 there was a serious accident on the old Giovi line in the Giovi tunnel which had a gradient of 2.6%. A train stalled, the driver was suffocated by smoke, and the train rolled backwards crashing into the following train. Thirteen people were killed. The Italian newspaper Il Secolo XIX so reported the event:"… il fumo in galleria asfissia i ferrovieri. Il treno abbandonato a se stesso ritorna a valle e va a schiantarsi contro un altro convoglio …".

III. The First Electric Railways in Italy

By the 1890s electric traction was technically possible, but there were many ways in which a railway might be electrified. The supply could be direct current, supplied through a third rail or through an overhead conductor or even, for shorter journeys, provided by batteries on the train.

Direct current motors had the advantages of good starting torque and easy speed control. DC traction was used on two Italian main-line railways in 1897. The Rete Mediterranea used railcars equipped with two 50 HP motors which ran at 50 km/h on the 13 km line from Milan to Monza, and the Rete Adriatica used similar railcars on the 43 km line from Bologna to San Felice.

The Rete Mediterranea, working in conjunction with the Thomson-Houston Company, then decided to electrify the 73 km line from Milan to Varese, and this started operation in 1901. The passenger railcars were similar to those on the urban tramways and had two 160 HP, 650 V DC motors. The supply was by third rail and the maximum speed was 100 km/h. A 13 kV three-phase transmission line carried electricity from the power plant to five AC/DC converter stations where the high voltage was reduced by transformers and then rectified by single-armature converters. In the early years goods trains were hauled by steam locomotives, but later, 640 HP electric locomotives were used. From 1905 the Officine meccaniche formerly Miami e Silvestri in Milan built 2000 HP 650 V locomotives using Brown Boveri electrical equipment.

The tramway-like low-voltage DC electric traction of the Varesina line operated perfectly, but the system was unsuitable for long lines because of its low efficiency and high capital cost.

The most robust electric motor, however, is the alternating current induction motor which may be single-phase or three-phase. The single-phase motor requires two connections, provided by the running rails and either a third rail or an overhead conductor as with direct current systems. The major disadvantage of the single-phase motor, however, is that, although it is robust and efficient, when running it has zero starting torque and so special arrangements have to be made for starting. The three-phase induction motor, however, produces its full torque on starting, but it has the disadvantage of requiring three supply connections, provided through the running rails which are earthed, and the other connections, which at high voltage, are provided by two overhead wires.

In 1898 the Rete Adriatica decided to conduct a large-scale experiment with high-voltage three-phase AC on its Valtellina line. This 106 km long mountain railway linked Lecco, on the eastern shore of Lake Como, with Colico where the line divided with one branch running north to Chiavenna and the other running east to Sondrio. Between Lecco and Sondrio about one third of the line was in tunnels and it had gradients of up to 2.2%. (Fig.3)

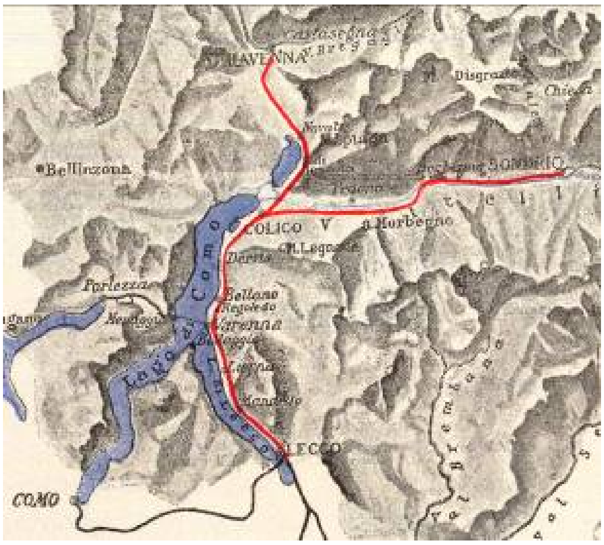

Figure 3. Map of the Valtellina line.

Despite the complication of requiring two overhead conductors, the Valtellina line was very successful. This ‘Italian system’ was a co-operative effort between Hungarian and Italian pioneers of AC technology, who had already worked together on other projects [1].

One of the people involved was the Italian Galileo Ferraris (1847-1897) who organized an international electrical exhibition in Turin in 1884. Exhibits there included the high-voltage transmission system of Gaulard and Gibbs, using what they called ‘secondary generators’ which were transformers with their primary windings all connected in series. Three engineers of the Hungarian Ganz company, Károly Zipernowsky (1853-1942), Miksa Deri (1854-1938) and Ottó Blathy (1860-1938), recognised the inadequacy of the series distribution system and of secondary generators and introduced parallel distribution using transformers with closed iron cores. The transformers were exhibited in Budapest in 1885, supplying lamps in an exhibition. Ferraris conducted comparative tests which showed the superiority of the transformer over the secondary generator. Ferraris was also interested in polyphase systems and in the idea of the induction motor.

In 1886 Ganz engineers built the Cerchi AC generating station, near the ruins of the Circus Maximus, and a high-voltage distribution network with transformers in Rome. In the following years several similar systems were established in Italian towns. These were all single-phase systems, but Kálmán Kandó (1869-1931), a young engineer in the Ganz company, was interested in the polyphase ideas which Ferraris had put forward and had worked on induction motors. Ganz was invited to supply the equipment for the Valtellina electrification. Kandó learned Italian and moved to Italy to direct the work. His achievement was later recognized by a plaque, written in Hungarian and in Italian, acknowledging his role in designing and building the world’s first high-voltage three-phase electric railway.

IV. Electric Traction for the Giovi Line

The terrible accident of 11 August 1898 near Genoa raised the question of the use of coal and steam for traction. The Carbonifera company, from Novi Ligure, which imported all the coal for Italian railways from Cardiff, tried hard to maintain its monopoly. At the same time the importance of the port of Genoa was increasing following the opening of the Suez canal (1869) as well of the tunnels crossing the Alps at Gothard (1882) and, later, at Simplon (1906). The railway from Genoa north to Turin and Milan was the busiest in Italy.

Steam traction was not adequate for the increasing traffic, and electric traction appeared as the natural solution. Various committees, including a committee of the new State Railway System, established in 1906, were set up to investigate the problem and make proposals for the electrification of the Giovi line [5, 6]. They did not choose a specific system of electrification, but invited three electrical companies to submit proposals: Ganz & Co (Budapest) because of the successful three-phase electrification of the Valtellina line, Brown Boveri (Baden) which had recently electrified the Simplon line using the three-phase system, and Westinghouse (Pittsburg) which, two days after applying, recruited two chief engineers of the Valtellina line, Pontecorvo and Kandó, and was about to set up a factory in Italy. Other companies asked to take part in the competition, including AEG Thomson Houston and Siemens Schuckert, which already had some experience in three-phase traction. After examining the application the proposal by Westinghouse was accepted.

The British technical journal *The Electrician* on 31 May 1907 published a report from the United States Consul at Milan giving details of the proposed electrification of the railway between Milan and Genoa at a cost of £9,400,000.[7] (Turin is not mentioned in the report). The trains were to be hauled by electric locomotives which would be combined with baggage cars, with two sets of trucks, having four axles, each axle being driven by a 300 HP motor. It would be possible to operate at a speed of about 54 miles an hour over the parts with a gradient of 1 in 125, and at a speed of 80 miles an hour on the level. Trains would have three cars, each carrying 50 persons, and the whole train would weigh 150 tons. ‘The express trains will take passengers from Milan to Genoa, or vice versa in 1½hours, while the locals will require 2½ hours. In this way there will be 20 trains per day, carrying an average of 6,000 persons. The 70 to 100 goods trains which will run every 24 hours will have combination locomotive and baggage cars of the same size and power as those of the passenger trains, and will put 30 wagons each weighing 22 tons which includes 12 tons of goods on each car, so that the train will pull in all 700 tons.’

A feature of the line was that, to prevent accidents, there were no level crossings along the route.

Works along the railway started in 1907[9].

The first section of line to come into operation with electric traction on 1 August 1910 was that between Pontedecimo and Busalla, where the accident had happened in 1898. The rest of the line between Genoa and Milan was electrified by 1915, though electrification only reached Turin in 1924.

While the construction work was in progress the newly established Societa Italiana Westinghouse replaced the previous Officine di Vado Ligure, and started to manufacture locomotives.

V. THE GIOVI LOCOMOTIVES

The type 550 locomotives for goods, called the 'Giovi Giants', were manufactured from 1908 to 1921 by the Società Italiana Westinghouse in Vado Ligure (Fig.4). 186 units of this locomotive were produced. It was the first electric locomotive produced in Italy in the workshops directed by Kalman Kando. It had small wheels (1.07 m in diameter), two wound rotor induction motor and two trolleys. It could operate at two speeds, 25 and 50 km/h, by parallel and series connections of the motors. (Series connection of two induction motors, which must have wound rotors, is achieved by connecting one directly to the main supply and feeding the second from the slip rings of the first, a system called concatenation). For starting and commutation a liquid rheostat was employed. Power was recovered during braking by allowing the decelerating train to drive the motors which then became generators and returned power to the supply system.

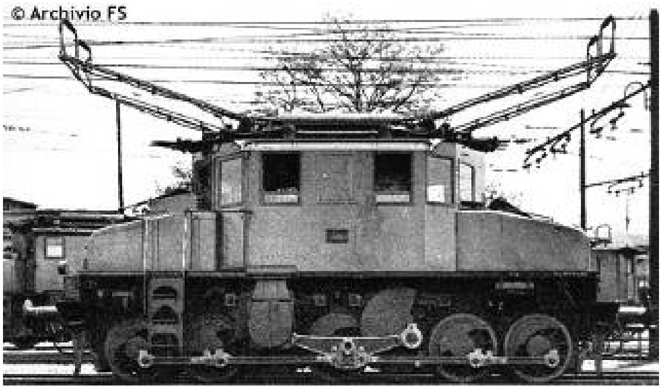

Figure 4. Figure 4. The 550 locomotive.

The 330 locomotive for passengers, called the 'Camel', was manufactured in Vado Ligure from 1914 by the Società Italiana Westinghouse and from 1919 by Tecnomasio Italiano Brown Boveri (Fig.5).

The main designers were Manu Stern, German, and Maurice Milch, Hungarian, under the leadership of Kalman Kando. The locomotive had big wheels (1.6 m in diameter) and two induction motors. It could operate at four speeds, 37, 50, 75, or 100 km/h, by changing the series-parallel connection and varying the number of poles (6 or 8).

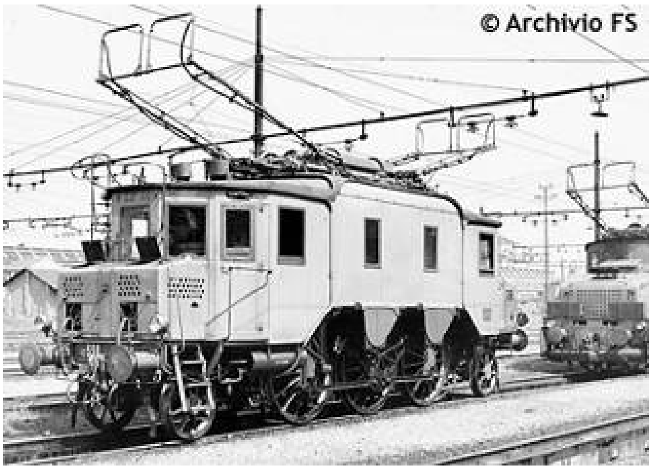

Figure 5. The 330 locomotive.

The locomotives are now permanently exhibited in the Milan Museum of Science and Technology.

VI. POWER STATION

A thermal power station was opened at Chiappella, near Genoa, in 1912 to supply the southern part of the railway[2]. The station included two three-phase generators (one of which was a reserve) rated 5000 kW (6000 kVA), 16⅔ Hz. The power produced was exclusively used for supplying trains along the railway. A special feature of the power station was the presence of a bank of three-phase water resistors which converted into heat the energy returned from the locomotives when the net load on the generators was negative.

Two parallel transmission lines (one being a reserve) connected the power station to four converter stations along the line. Each had four step-down 750 kVA transformers (three in operation, one as a reserve). A lack of power along the line occurred very rarely.

A comparison of the cost of operation of the old steam railway and the new electric one is reported in [5].

VII. THE SUCCESS OF THE GIOVI LINE ELECTRIFICATION

The Hungarian engineer Lászlò Verebélÿ studied the benefits obtained by electrifying the line, and published a paper about it in 1920 [2]. Electric trains could be spaced more closely than the steam-powered trains so that the capacity of the line was increased. A third parallel line had been considered, but with electrification it was not needed, so there was a major saving in capital cost.

Verebélÿ calculated the economic benefit of using regenerative braking. Given two trains, one going uphill and one down, there could be an energy saving of 50%. With a single train the energy saving over the whole route was 18%. The use of regenerative braking gave an extra 5 to 6% return on the capital invested in the railway. Regenerative braking also reduced wear on the mechanical brakes, thus reducing maintenance costs, increasing reliability and ensuring that mechanical brakes were instantly available in any emergency.

VIII. CONCLUSIONS

The story of the Giovi line is an important part of railway history [10]. The electrification of the Valtellina line had demonstrated that using three-phase induction motors to power a train was perfectly practical. The requirement for two overhead wires did not create excessive problems at junctions. It had also shown the possibility and the significant benefits of regenerative braking.

The installation on the Giovi line demonstrated that the same technology could be used on a very heavily loaded line, with the same benefits, and that the capacity of the line could be greatly increased compared with when steam traction was employed.

Most electric railways today use either DC or single-phase AC supplies which feed the motors through electronic control systems. As with the Giovi line, however, the motors are induction machines and power is recovered though regenerative action when the train is slowing or running downhill.

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