First Integrated Electric Power System in Croatia

Marko Delimar*, *Senior Member IEEE*; Aleksandar Szabo*, *Senior Member IEEE*;
Luka Lugarić*, *Student Member IEEE*
* University of Zagreb, FER, Croatia, e-mail: *m.delimar@ieee.org*

***Abstract*— Significant developments occurred in the field of electric power engineering at the end of 19th century. At the time of Tesla's Niagara Falls power plant and first power systems in Europe, little is known about electric power system developments in Croatia. This paper presents historical background and activities associated with the first electric power system in Croatia - power plant and transmission line Krka - Šibenik which began operation in 1895.**

***Keywords*—power systems history, first power system, Europe, Croatia**

I. Introduction

At the end of 19th century there have been significant developments in the field of electrical engineering. With the opening of the Pearl Street station in lower Manhattan on 4 September 1882, Thomas Edison publicly presented a complete system of commercial electric lighting and power [1].

First electrical power plants, which produced direct current, were built in city centers. In 1887 there were 121 DC power stations in the USA that delivered DC electricity to customers. Primary function of these plants was to provide power supply necessary for lighting. However, it became apparent that high amounts of DC power could not be transmitted at greater distances without introducing excessive voltage drops. The three-wire distribution system provided some improvement in voltage drop and conductor sizes, but did not eliminate the problem.

Generating power close to where it was consumed and installing large conductors to handle the growing demand for electricity quickly proved an economical letdown. Due to predominant use for lighting at night, plant load during the day was distinctly unbalanced. To balance generation and consumption during 24 hours, it was necessary to use accumulator batteries, which were being charged during the day and discharged at night during peak loads. Besides maintaining constant voltage, the biggest problems were transmission losses, hindering connections with consumers situated far from the source. In this phase of electric power system development, such systems could not be considered integrated power systems, which would, together with generation and consumption, include transmission and distribution of generated power.

The alternating current systems brought along a solution to transmitting electrical energy to greater distances with easy transformation to higher voltages. It was shown that by increasing voltage, transmission losses were made lower. In 1893, World's Fair, Chicago, was the venue of Westinghouse's all-inclusive system [2]. First large scale power plant at Niagara Falls had three 2-phase generators. Each generator had 5000 HPs, nominal voltage of 2200 V and nominal frequency of 25 Hz. This power plant was put in operation on 26. August 1895, only 2 days before first power system in Croatia began operating. It should be noted that transmission of electrical power from Niagara Falls to 43 km distant Buffalo was not in operation before 1896.

In the period from 1885 to 1895, during the "War of the currents" [3] Edison advocated his concept, DC systems, while Tesla and Westinghouse pleaded AC systems were superior. At his address to the AIEE (today IEEE), Nikola Tesla proposed the use of step-up transformers, which would allow transmission at higher voltages. Using AC, generated power could be transformed to a higher voltage at power plants, transmitted over long distances and then transformed to lower voltages for use within cities. Numerous other improvements and inventions contributed to AC, such as transformers, distribution systems and alternating motors. Due to the fact that power losses are significantly reduced with increasing transmission voltage, AC system triumphed.

Significant steps in developing AC systems were being taken in Europe. In 1884, at the "Esposizione Generale Italiana" [4] , first long range transmission of electricity was exhibited, using the new AC system by means of an alternator made by Siemens. The alternator was operating at 2000 V, 133 Hz and transmitted power to a distance of 40 km [5].

In Torino, Zipernowsky, Deri and Blathy of the Hungarian company Ganz from Budapest, exhibited a self-exciting alternating generator [6]. They were researching ways of increasing efficiency of electrical power transmission and experimented with power supplies and current transformation. This led to the invention of the ZBD alternating current transformer in 1885, a system based on a closed iron ring core with an arbitrary diameter and a coil around the core, which conducts AC current. The system converted higher voltage suitable for energy transmission to lower "service"-level voltage (step-down transformer).

These engineers invented the transformer in the form as we know it today. This was the solution to the problem of transmission and distribution of electric power. The same trio applied their patents in the first AC power plants and grids, including the first power system in Croatia in 1895.

One of the first significant commercial long distance transmissions was the one from Tivoli power plant to the 28 km remote Rome. The project began in 1890 and was set in operation in 1892. It was a one-phase system from the Hungarian company Ganz. At the International Electrical Exposition in Frankfurt am Main, which had great impact on development of electrical engineering and technology in the world, a three-phase AC transmission was conducted between Lauffen hydro plant to the 175 km distant Frankfurt [7].

Ganz developed two-phase systems in Europe and also installed such a system into the first Croatian hydro-plant at Krka river, near Šibenik [8].

II. Development of Power Systems in Croatia

For the purposes of presenting the development of the Croatian power system, a short historical overview is given. At the time, Croatia was a part of the Austro-Hungarian Monarchy. Significant events in development of electric power systems in the world and in Croatia before 1914 are presented in Fig. 1.

Initial electrification and first DC power plants in Croatia started in 1884 in cities. For example, the first electric lightning system was seen in Rijeka, on the grand opening of the new city theatre, featuring the premiere of Verdi's "Aida" on 5 October 1885 [9].

First one-phase AC power plant in Croatia was built in Rijeka harbor in 1892 [10]. Its primary purpose was to supply power to winch motors, harbor cranes and local lighting. There was no transmission system for a larger distance in place yet, so there can be no discussion of an integrated system, such as Krka – Šibenik.

A. Krka-Šibenik – first integrated power system

First AC power system, consisting of generation, transmission and distribution Krka - Šibenik was built and set in operation on 28 August 1895. Builders of the two-phase Krka - Šibenik power system, first integrated power system in Croatia, were Ante Šupuk, his son Marko and Vjekoslav Meichsner [8]. Ante Šupuk was the Mayor of Šibenik and representative of Dalmatia in Emperors Council in Vienna, and his son Marko was a naval captain. Vjekoslav Meichsner was a civil engineer and municipal measurer. Preparations for constructions were conducted in 1891 through 1893. Meichsner prepared the project and blueprints to build the hydro-plant and the transmission line for connection with Šibenik. Constructing the hydro plant took only 16 months, and all work was done by domestic contractors. It used a head of water of 10 m, although it had a permit to use 25,8 m. Company "Šupuk and Meichsner - First Privileged Power Plant in Dalmatia "Krka" started operating on 1 June 1895.

Historical importance of this hydro plant is in the fact that it was a two-phase plant while at the same time larger European cities such as Frankfurt, London and Rome still had one-phase systems. At the time, it was believed that multi-phase systems were less secure. Eventually, in due time, other cities also adopted multi-phase systems.

Krka power plant (later named Jaruga 1) had a vertical Gerard turbine. Two-phase alternator manufactured in Ganz had 320 HP, rotated at 315 rpm and produced voltage at a frequency of 42 Hz. Nominal voltage of 3 kV was directly connected to the power line towards Šibenik, 11 km long. It's protection was minimal. Consequently, every larger atmospheric discharge would destroy generator coils and caused malfunctions and disruptions. Simultaneously with building the power plant (Fig. 2), the transmission line was constructed (Fig. 3). By using the same wooden poles for telephone lines the line was installed between Meichsner's mansion in the city and hydro plant. Municipal distribution grid 3000/110 V was constructed, which included 2 breaker substations and 6 transformer substations. The plant location is shown in Fig. 4.

Krka power plant was in operation for 19 years, from 1895 to 1914, when both the plant and the power line were dismantled by the Austro-Hungarian army to use the copper, while the power plant Jaruga 2 was improved and maintained operation.

The previously mentioned, second hydro power plant, Jaruga 2, was built in 1903, also by Ganz. It was set in operation on 3 December 1903 for the calcium carbide factory in Crnica. The factory had 12 one-phase electrical furnaces, of similar power as the newly built Jaruga 2 plant. The plant had two pressure tunnels 2,6 m in diameter, each 26,35 m long, capable of letting through a maximal flow of 15 m^3/s.

B. Manojlovac-Šibenik – first three phase system

Construction of the first three-phase system, based on the hydro plant Manojlovac and connecting to the city of Šibenik began in 1902, finished in 1905 and set to operation in 1906, as Crnica factory expanded to a total of 30 furnaces. Hydro plant's intalled power was 20,8 MVA, produced from four horizontal Francis turbines with double rotors of 6000 HP and 420 rpm. Every shaft supplied mechanical power to three Ganz generators. Each generator had a nominal power of 5300 kVA, voltage 30 kV and frequency 42 Hz. This entire system operated on nominal voltage of 30 kV without voltage transformation at the power plant side. Double three-phase power line, placed on wooden poles, had two conductors, 3 x 62 mm^2 in cross-section, made of massive copper. The line was 35 km long.

There are several interesting facts regarding

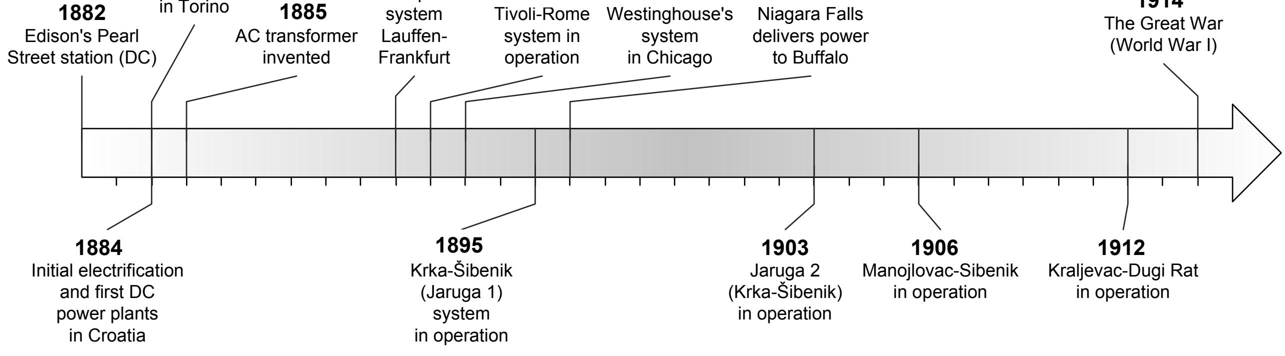

Fig. 1. Electricity developments in Croatia

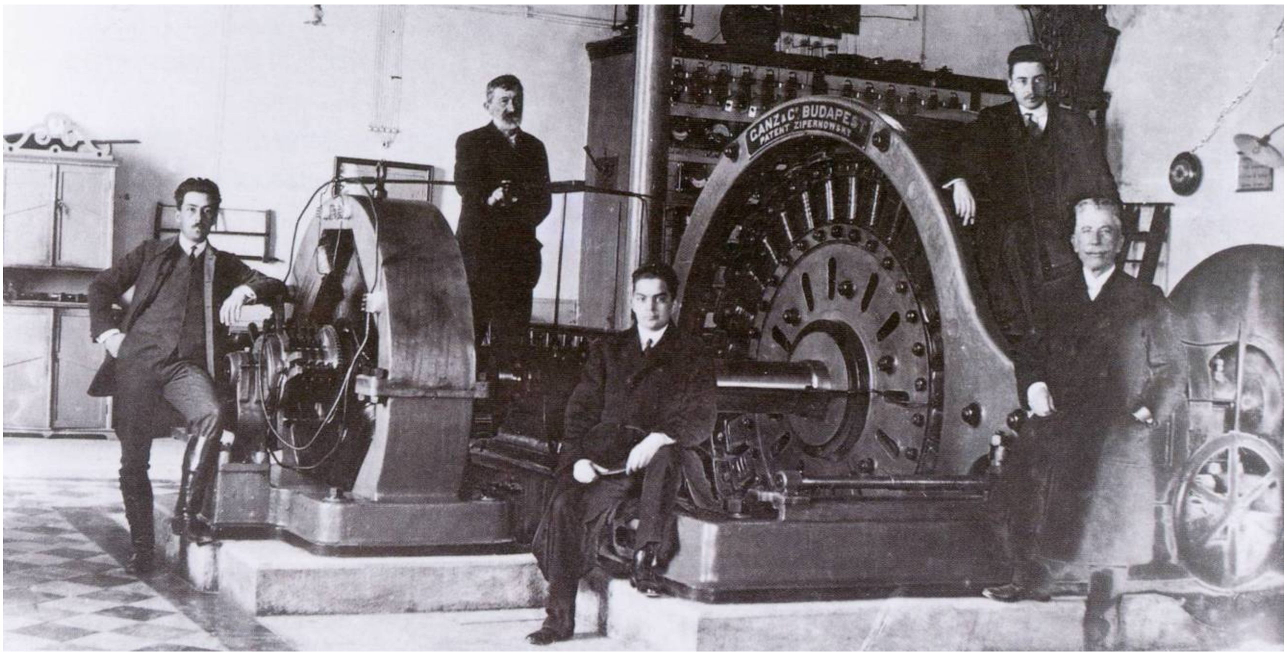

Fig. 2. Šupuk family and associates, photographed with the Krka hydro plant generator (taken from [8])

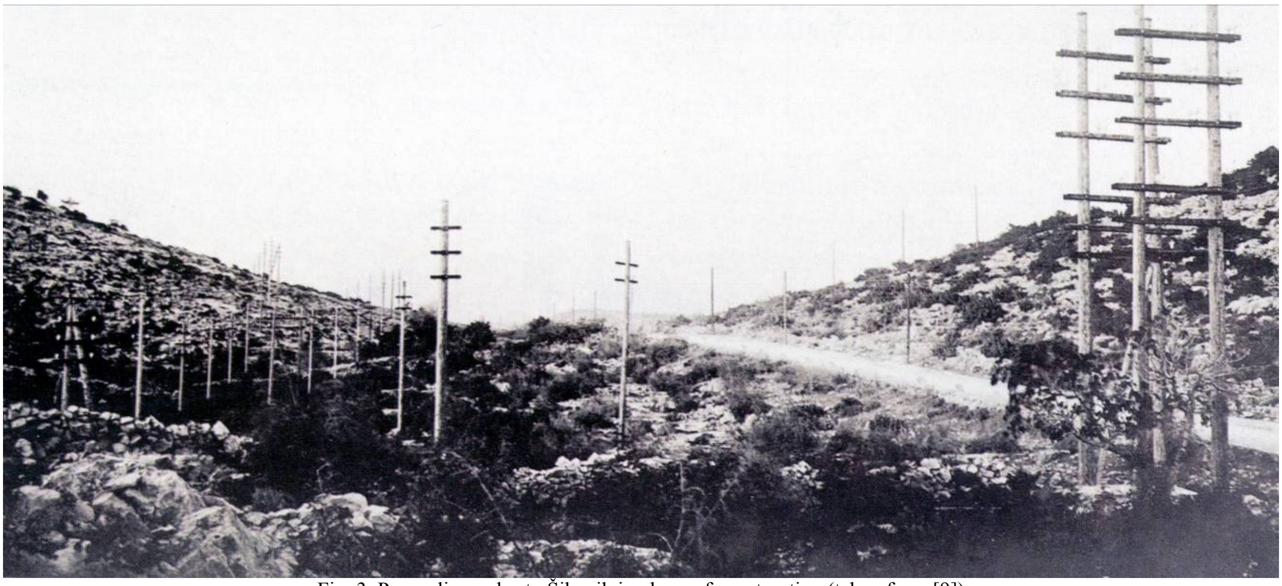

Fig. 3. Power line poles to Šibenik in phase of construction (taken from [9])

Manojlovac hydro plant. The 30 kV nominal voltage was the highest generator voltage in Europe, and remained such until 1947 when standard generator output voltages were reduced to 6 kV. Since the generators were directly connected to the power line, atmospheric discharges freqently caused generator coils to fuse. Replacing generator coils thus became a usual operating procedure. Since there were no circuit breakers synchronizing generators was not possible. Keeping an equal number of rotations between generators was done by the operator which used just his hearing to compare and equalize sound pitch coming from respective generators.

Since poles were wooden, every lightning strike or line-to-earth short circuit caused them to burn up. They were later gradually replaced by pylons made of steel. Insulators which supported the power line frequently breached. To repair this, the whole system had to be shut down. The power line was then slowly energized by increasing excitation of one generator to determine which of the power lines caused malfunction, so it would be easier to detect the breached insulator. All three lines would then be energized, regardless of the order of phases or whether the three lines belonged to the same three phase system. Before each system restart, the factory in Crnica had to be notified so that lines would be rearranged in it in the same manner.

Due to this mode of operation, Manojlovac did not play a significant role in introducing electric power to the surrounding areas. This is the reason the sole consumer was Crnica factory, and system load depended only on the number of factory's furnaces in operation. For the same reason, the owner of the factory, the hydro plant and the

Fig. 4. Hydro plant Jaruga 1 in 1094 (taken from [12])

transmission line was the same. The system operated in the same manner for the following 40 years.

C. Kraljevac – Dugi Rat

Built to supply a factory of carbide and cyanimide in Dugi Rat, the first phase of hydro plant Kraljevac was constructed in 1912 on the Cetina river near Omiš. It was one among the largest in Europe at that time.

Two Francis turbines, nominal power 18000 HP, rotated at 375 rpm, supplied mechanical power to two generators of nominal power 16000 kVA, $\cos\varphi = 0.8$, nominal power 4 kV and frequency 50 Hz.

As in previously described systems, no circuit breakers were installed on the generator or the transmission line. System shut down was performed by reducing generator excitation.

In its initial phase, installed power was a total 32 MVA. Output voltage was transformed within the plant by two water cooled, oil transformers of 16 MVA, from 4 kV to 56 kV. At the time when they were set in operation in 1912 these trasformers were the largest in the world.

Electric power was transmitted to the factory in Dugi Rat near Omiš by a 23 km transmission line. Due to losses which amounted to 7.85%, voltage delivered to the factory was only 51.6 kV, where it was transformed to 15 kV.

The second phase of the construction of Kraljevac was done after The Great War (WWI), when another two 30000 HP turbines and 26000 kVA generators were installed.

III. Discussion and Conclusions

Croatia had several pioneers in the field of electrical engineering; for example Franjo Hanaman, in cooperation with Alexander Just, perfected lighting bulbs with metal filaments [11], which resulted in wolfram bulb patent in 1903. One of the best known scientists and inventors in the field of electrical engineering, Nikola Tesla, was born in Smiljan near Gospić, about 100 km north of Šibenik. It is curious that in May 1892, Tesla held a lecture on AC in the City Hall of Zagreb, at the same time of major preparations to build the Krka - Šibenik hydro plant.

The Krka-Šibenik (Jaruga 1) two phase power system was among the first integrated power systems in the world and presents an interesting milestone in the development of electrical power engineering. Several power plants were subsequently built in the area, where the three phase power plant Manojlovac, operating at the generation voltage of 30 kV, is one of the most interesting plants ever built.

References

[1] IEEE Virtual Museum, “Pearl Street Station: The Dawn of Commercial Electric Power”, [Online], available at: http://www.ieee-virtual-museum.org, [05 March 2007]

[2] B, Bowers, “Roman engineering (overhead power line history)“, *Proceedings of the IEEE*, Feb 2003, Vol. 91, Issue 2, pp. 357- 359

[3] T. McNichol, “AC/DC: The Savage Tale of the First Standards War”, Jossey-Bass, San Francisco, 2006

[4] U. Levra, R. Roccia, “Le esposizioni torinesi 1805 - 1911. Specchio del progresso e macchina del consenso”, Torino City Archive, Torino, 2003.

[5] F. Steinle, “Theorienantagonismus, Elektrotechnik, Gasentlad-ungen, das Elektron”, Universität Bern, Bern, 27 June 2002.

[6] Ganz Transelektro Electric Co. Ltd., “History of the company”, [Online], available at: http://www.ganztrans.hu, [05 March 2007]

[7] J. Jones: “Empires of Light: Edison, Tesla, Westinghouse, and the Race to Electrify the World”, Random House, 19 August 2003

[8] B. Markovčić, I. Prpić, F. Plic, A. Busatto: “Razvoj elektrifikacije Hrvatske”, Part I, Institut za elektroprivredu, Zagreb, 1984

[9] Hrvatska Elektroprivreda, “Stoljece hrvatske elektroprivrede”, Zagreb, 1995

[10] S. Szabo, “Nikola Tesla in Zagreb”, *ABC tehnike*, Zagreb, March 2006, pp 3-6

[11] M. Kastelan-Macan, “Uz 100. obljetnicu Hanamanova patenta”, Almae Matris Alumni Chemicae Ingeniariae Zagrebiensis Bulletin, Zagreb, December 2003.

[12] J. Moser, “Šibensko Munjivo”, Juraj Sizgoric City Library, Sibenik, 1998.