THREE-PHASE CURRENT _

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DOI: 10.15199/180.2021.3.3

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THE POLE, WHOM WE OWE THREE-PHASE CURRENT

POLAK, KTÓREMU ŚWIAT ZAWDZIĘCZA PRĄD TRÓJFAZOWY

Summary: The article presents the profile and achievements of Michał Doliwo-Dobrowolski, a Polish inventor born in Russia. He played an outstanding role in the history of world electrical engineering at the turn of the 19th and 20th centuries. He was a pioneer of the three-phase current technique. In 1888, he constructed a sensational, easy to use, cheap to produce and operate, the world's first three-phase squirrel-cage induction motor. The patent, filed on March 8, 1889, started a new era in electricity, which continues to this day, the era of alternating current.

Keywords: three-phase current, electricity, three-phase generator, three-phase motor, phasemeter, frequency meter, three-phase transformer

The man, to whom various nationalities are ascribed

Three-phase current is nowadays generally used all over the world. It has numerous advantages; therefore, it is applied universally - especially, for transfer of electric energy to long distances. Only some people, however, know that Michał Doliwo-Dobrowolski was the creator of the idea of three-phase current generators, electrical transformers, transfer lines, and even presently universally employed three-phase engines. When describing his silhouette and achievements, the author of the present development will stubbornly state that he was the Pole. In many elaborations concerning the history of electric engineering, he has been described as the German because in Germany he made his memorable discoveries and presented them on public forum as the representative of German institutions. Moreover, he had initially strong connections with Russia as his mother, Olga Mihajlovna, was the Russian. The future inventor was born in 1862 in Gatczyn near Sankt Petersburg, so the language of his childhood was Russian. However, his father, Józef, was undoubtedly Polish nobleman (Doliwa coat of arms). We may also put here a small question mark at this point because the father of the future genius served in the Russian army, was a colonel and participated in the Crimean War. He did not expose too much his Polish origin as it was an obstacle in his career. However, in the time of challenge, when being the Pole caused repressions to the family, he chose Polishness and emigrated from Russia.

Streszczenie: Artykuł przedstawia sylwetkę i dokonania Michała Doliwo-Dobrowolskiego, polskiego wynalazcy urodzonego w Rosji. Odegrał on wybitną rolę w historii światowej elektrotechniki na przełomie XIX i XX wieku. Był pionierem techniki prądu trójfazowego. W 1888 r. konstruował rewelacyjny, prosty w obsłudze, tani w produkcji i eksploatacji, pierwszy na świecie trójfazowy indukcyjny silnik klatkowy. Patent zgłoszony 8 marca 1889 r., zapoczątkował nową erę w elektryce, trwającą do dziś, epokę prądu przemiennego.

Słowa kluczowe: prąd trójfazowy, energia elektryczna, prądnica trójfazowa, silnik trójfazowy, fazomierz, częstościomierz, transformator trójfazowy



Fig. 1. Michał Doliwo-Dobrowolski [1] Source: Deutsches Museum Bildarchiv

But it occurred later, when Michał Doliwo-Dobrowolski, as 16 years (!) old boy, commenced (in 1878) the studies at Institute of Technology in Riga.

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His initial education was based upon the Russian language as he graduated a secondary school in Odessa. He undertook the studies in Riga (in Russian language) due to a lack of alternative possibilities; purely Polish higher education institutions did not exist at that time; even in Warsaw, where there was the Russian-language **Imperial** University of Warsaw.

Probably Michał Doliwo-Dobrowolski would have graduated the University of Technology in Riga and – similarly as his father - would have made a carrier in the Russian Empire but an accident happened on 13 March, 1881 in Petersburg: Tsar Alexander II was murdered. Polish student, Ignacy Hryniewiecki was the assassinator; this fact commenced a series of repressions against the Poles. In such context, Dobrowolski (who had nothing to do with the mentioned assassination) was expelled from the University of Technology in Riga in 1881 exclusively due to the fact that he was the Pole!.

Emigration to Germany

After expelling from the Riga University, Michał Doliwo-Dobrowolski tried to continue his education as a free student in Petersburg, Odessa and Novorossiysk but everywhere his Polish descent was an aggravating factor. When he became deprived of the possibility of obtaining education and decent employment in the country of his birth, Michal Doliwo-Dobrowolski decided to emigrate.

In 1883, he moved for Germany where he immediately undertook further studies at the University of Technology in Darmstadt. At first, he studied at the faculty of mechanical engineering and then, at the newly created faculty of electric engineering. He graduated in 1884 (one year after beginning of his studies). He commenced the employment at the mentioned university as its outstanding graduate. In the period of 1884–1887, he worked under the guidance of professor of electric engineering, **Erasmus Kittler**, and was occupied in, inter alia, electric chemistry and electroplating. It did not, however, inspire him, so he made himself independent and moved to *Allgemeine Elektrizität Gesellschaft* (AEG) and stayed there for a longer period of time and created his key inven-



Fig. 2. Michał Doliwo-Dobrowolski, photo pobably taken in 1883 when he was a student in Darmstadt (Germany) [2] Source: https://www.wikiwand.com



Fig. 3. Michał Doliwo-Dobrowolski (first from the right) as a student and later an assistant to prof. Erazm Kittler (in the center) - head of the Department of Electrical Engineering in Darmstadt [3]

Source: https://de.wikipedia.org/wiki/Erasmus_Kittler

tories. It should be stressed that Prof. Kittler made a beautiful gesture; instead of disturbing the young man to leave his faculty, he supported his efforts in AEG and gave him a very good certificate. Owing to this fact, the Director General of AEG, Emil Rathenau gave him a freedom in conducting the studies; Dobrowolski focused his attention on the problems of alternate currents. In 1888 he constructed the world's first three-phase current generator.

What were the advantages of three-phase current?

At this moment, we should remind the historical background. The first commercially used generators produced a **direct current**. Such current was produced by the world's first electric power plant, constructed in 1882 by **Thomas Alva Edison**. The mentioned factory delivered current to 7200 electric bulbs at Manhattan. The direct current worked and delivered profits but its transmission to bid distances was connected with the energy losses. Edison promised the reward of 50 thousand US dollars to the person, who would be able to decrease the mentioned losses.

Nikola Tesla, the Croatian immigrant to the USA found the solution. He became employed at Edison's (whom he admired very much!) company in 1886 and in 1887 he submitted the solution of the mentioned above problem: the losses will be radically lower when the alternating current is produced and transmitted.

Edison was a sworn enemy of alternating current, so he did not accept the solution, did not pay the reward and their paths definitely diverged. The inventory of Tesla occurred to be revelation and when he found a "sponsor, **George Westinghouse**, co-owner of Western Union Company, the alternating current began to be popular. The solutions of Tesla assumed, however, the application of one-phase current what significantly limited their suitability.

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Later on, Tesla employed two-phase current (single-phase electric engines did not want to start up) but they were not successful ideas.

On such background, the concept of **three-phase current** generator by Dobrowolski was technical revelation. Three-phase current may be generated more effectively. The three-phase generator of the same size. The transmitting three-phase line is constructed from lines which weigh and cost by 25% less than the single-phase line, transmitting the same energy. The three-phase motors are cheaper and simpler in construction as compared to the singlephase ones; they have better efficiency and lower vibrations. Three-phase transformers have a compact construction and are more convenient in comparison to the single-phase equipment. In case of three-phase system, we may introduce the current to single-phase receivers (such are found in our flats) and they may occur in 3-times higher quantities.



Fig. 5. Michail Dolivo-Dobrowolsky with colleagues at AEG in Berlin [5] Source: https://de.wikipedia.org/wiki/Michail_Ossipowitsch_Doliwo-Dobrowolski

From inventory to application



Fig. 4. A three-phase engine by Michał Doliwo-Dobrowolski from 1891 [4] Source: http://apw.ee.pw.edu.pl

It is a long list of the advantages of three-phase current but there is no use to name them here; it is sufficient to say that it was the inventory of outstanding meaning in the fates of electric engineering.

Cascade of the inventories

A positive receipt of the achievements of Michał Doliwo-Dobrowolski in AEG company caused that "he spread the wings" and the inventories were "pouring from him". In 1889, he constructed three-phase induction engine with squirrel-cage rotor, being a prototype of most of the to-day used asynchronic engines (patent application 8.3. 1889). He obtained also some key patents on three-phase transformers (German patent no 56359 of 29.08. 1889 and the next one of 4.10. 1891). Doliwo-Dobrowolski developed new measuring instruments (phase meter and wattmeter). He found the method for extinction of discharge in high tension switches (the so-called quench chambers). The list of the inventories was long and the year 1889 was undoubtedly most abundant in the whole professional career of our countryman. But we had to wait still for the effects.... In spite of a great substantial value, the achievements of Michał Doliwo-Dobrowolski met the obstacles. The main ones were related with the practical application of the inventories, or their transfer to practice. It happens only in the fairy tales and in imagination of the laics that a genial inventory is quickly and efficiently introduced to practice "for the sake of humanity". In fact, there is one high threshold between the scientific inventory and its universally available application, i.e. economy. To make the inventory popular, it is necessary that someone might gain the profits from such popularization. Unfortunately, in the case of the discoveries of Michał Doliwo-Dobrowolski there were many who would state a loss due to the popularization of his inventories.

The authority of Edison was so high that by the end of the 19th century there were many electric power plants constructed and they produced and sold the direct current according to his technology. Until 1886, in Canada and the USA about 50 such power stations were constructed; until 1888, their number was equal to more than 200. Edison himself constructed 121 power plants in total. There were hundreds of them all over the world, including also a significant number in Germany. No wonder that energy companies did not want to close newly erected power plants and seek for other solutions, even if they were decisively the better ones. In order to get in the market with the new discoveries, AEG and Swiss Oerlikon (which also invested in the studies of Dobrowolski) decided to show his achievements during the World Electric Engineering Exhibition in 1891, held in Frankfurt/Main.

The crucial show at the Exhibition

During the mentioned above exhibition, AEG company presented a set of different three-phase devices which caused a great interest. Michał Doliwo-Dobrowoslki himself submitted three-phase engine with power of 100 HP which was then the greatest size over the world. The mentioned engine operated the pump which served for generation of 10-m high waterfall, illuminated with the light of 1000 electric bulbs.

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But it was not the most important fact.

The sensation arose from the fact that the inventor fed the mentioned engine via the three-phase energy line of 175 km length, transmitting the current from hydro energy plant (three-phase, of course) in Lauffen. It was easy to build the power plant as well as the objects which were to be fed at the exhibition but the energetic line was a serious problem. To construct it, the whole army of telephony and telegraphy specialists was employed (they constructed earlier the overhead lines of communication conduits); 3283 pillars were erected in total on which – using ceramic insulators – there were suspended the lines, transmitting very high voltage (at the discussed time) of 15.000 V.



Fig. 6. Generator of the power plant in Lauffen am Neckar (contemporary wood engraving) [5]

Source: https://de.wikipedia.org/wiki/Michail_Ossipowitsch_Doliwo-Dobrowolski

The obstacles to be overcome were not only of technical nature. The people were afraid of high-voltage line and it was necessary to obtain the consent of the owners of thousands of land plots and, additionally, of the administration of four states, entering the composition of Germany! To calm down the emotions, Michał Doliwo-Dobrowolski assembled the commission (including also journalists who described it later on) before which he demonstrated personally that his energetic line was not dangerous. First, a full voltage on the wires was switched on and then, one of them was broken and the inventor himself came and took it up from the ground, using bare hands. If the residual current circuit breakers (invented by him) in power plant (used until now) had not worked, it would have been his last moment of life... It ended with success, there was no current in the wire, the automatic device reacted correctly, and Michał Doliwo-Dobrowolski survived and convinced the sceptics that his energetic line of alternating current did not pose any danger.

It should be added that more or less at the same time, Edison (the obstinate enemy of alternating current) tried to prove something completely different. To show how much the alternating current was dangerous, he arranged the shows during which he electrocuted dogs, cats, horses and cows – and even orangutan. Moreover, in January 1903, he electrocuted (6000V!) female elephant from Luna Park Zoo in Coney Island, at the presence of "audience", consisting of 1500 persons. He wanted also to perform the public execution of man (William Kemmeler, murderer, being sentenced for death on the electric chair) on electric chair but fortunately, it did not occur.

In spite of the Edison's campaign and unfavourable conditions coming from the existing energy plants, the exhibition in Frankfurt and the related international congress of electric engineers have ended with the success of three-phase current and personally, of Michał Doliwo-Dobrowolski.

Scientific success becomes changed into business success

The exhibition in Frankfurt decided on the direction of development of electric engineering and electronics. Building of direct current and of single or two-phase power plants was abandoned. Everywhere, three-phase power plants were constructed. Michał Doliwo-Dobrowolski was the outstanding scientist and inventor but he also marked his participation in development of practical electric engineering. In 1895, he constructed the world's first three-phase water power plant on the Rhine river (in Rheinfelden), modifying principally the earlier employed generator which worked in Lauffen. The difficulty consisted in the fact that water turbines were slowly rotating and earlier constructed generators functioned well when had a quickly rotating drive (for example, of steam engine). Dobrowolski solved the mentioned problem and his construction was later copied in many power plants all over the world.

In 1897, he designed also three-phase power plants for Silesian cities Zabrze and Chorzow. It sounds nicely for Polish ears but we let's not forget that in the 19th century the mentioned cities belonged to Germany.

At the discussed period, Russia – the country of his birth, remembered the inventor. He was offered the function of the first dean in newly created, Russia's first Department of Electrical Engineering of the Petersburg University of Technology. Dobrowolski did not accept the mentioned function but consulted the matters of the seat of the Department, the program of the studies and purchase of equipment; he also donated his private collection of professional literature to the Department.

There were also noticed various signs of recognition for the achievements of Michał Doliwo-Dobrowolski. It is worthy to mention here Gold Medal of the World Exhibition in Paris and his election to three commissions in Verband Deutscher Elektrotechniker VDE (Association of German Electric Engineers). In 1908, AEG concern nominated him as a director of electrotechnical manufacturing plant in Berlin. In 1911, he was also distinguished by *honoris causa* doctorate of the University of Technology in Darmstadt.

The success has many fathers, so the doubts were risen up

As it was mentioned above, the beginning of the $20^{\rm th}$ century was connected with the numerous words of recognition for

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the achievements of Michał Doliwo-Dobrowolski but also, with the claims that his contribution to development of electrical engineering was not so much important as was stated by his followers.

It is known that if anyone succeeds, there are always those who want to discredit the mentioned success. The dispute whether the three-phase system may be referred exclusively to the person of Michał Doliwo-Dobrowolski appeared quite often in professional literature and publicist papers at the beginning of the 20th century.

There were indicated the studies of G. Ferraris who created the theory of rotating magnetic field, being the basis for functioning of generators of motors of Dobrowolski. There was also mentioned C. Bradley, who owned the patent for a similar solution as that one by Michał Doliwo-Dobrowolski, but he has never implemented it in practice. The Americans were most obstinate and indicated the studies of mentioned above Nikola Tesla, who was oriented to the same direction but he did not create a technical solution, having a practical meaning. The dispute on the mentioned subject was settled definitely by the special VDE commission which published (in 1957) the univocal opinion, indicating Michał Doliwo-

Dobrowolski as the creator of three-phase electric engineering systems.

Unfortunately, the author of the described above achievements did not see this moment. The period of the World War I deteriorated much his health. After termination of the war but before undertaking again his work at the University of Technology in Darmstadt, he became infected with the "Spanish" flu and died on 15, October 1919. But he lives in the grateful memory of all electricians!.

References

- [1] Deutsches Museum Bildarchiv;
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Article reviewed Received: 16.08.2021 r./Accepted: 23.08.2021 r.

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