Resonance methods of electric power transmission

(Devoted to the memory of Nikola Tesla, /10 july 1856 – 7 january 1943/)

D.S. Strebkov,

Academy of Agricultural Sciences of the Russian Federation

All-Russian Institute for electrification of Agriculture

1st Veshniakovsky proezd, 2, Moscow, 109456, Russia

+7-495-171-19-20

Fig. 2. Professor D.S. Strebkov next to the historic marker in honour of N. Tesla in Colorado-Springs, 27 February 2004.

One hundred seven years ago Nikola Tesla published the results of his experiments on the resonance method of electric power transmission [1, 2]. Today only a historic marker is left from his famous electrical laboratory in Colorado-Springs, USA (Fig. 1, 2); his patents are unknown, and Tesla's transformer was mentioned in manuals of electrotechnology only up to 1940 [3, 4].

Resonance methods of electric power transmission were found useful for high frequencies in radio engineering and communication engineering and they are also used on low frequencies in electrothermics.

In the beginning of the XX century, there were no diodes, transistors, lasers, TV and solar batteries; and three-phase networks on frequency of 50-60 Hertz successfully coped with the task of transferring electric power in quantities ranging from some W to thousands of megaW for a distance of 100 - 1,000 kilometers [5]. Due to this, Tesla's works on electric power transmission have been gradually forgotten since his death [6].

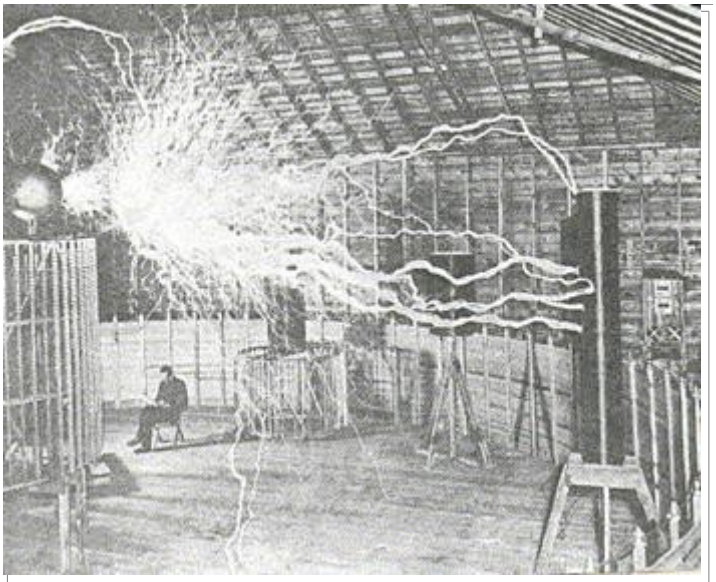


Fig. 1. N. Tesla in his laboratory in Colorado-Springs, 25 - 31 December 1899. [2]. The picture is published with the permission of N. Tesla's museum in Belgrade.

In connection with development of integrated power systems in Europe, North and South America and suggestions on the creation of a global power grid of Earth, problems of designing devices for transmission teraW transcontinental flow of electric power appeared [7, 8]. Problems of electromagnetic safety and reliability of power supply along with the quickly growing cost of lands can be completely solved during the change from air transmission facilities to cable high-voltage lines. But cable systems of electric power transmission for a long distance are possible today only using direct current. The third method can interfere in the competition between systems of electric power transfer using direct and alternating current: the resonance waveguide method of electric power transmission on heightened frequency, which was proposed by Tesla in 1897 for the first time [9].

In the thirties of the XX century, the theoretical basis of the use of a single conductor as the waveguide in order to transfer electric power on high frequency was developed [10].

Current in cylindrical waveguides is closed in the form of displacement currents flowing along the waveguide's axis; and current in the single waveguide is closed in the form of displacement currents in the environment around the conductor. In connection with the presence of a phase difference between, waves of current and voltage, surface charges appear on the surface of the single opened conductor. They create coulomb exciting electric fields and these fields lead to the occurrence of coulomb currents in the conductor [11]. Thus, a potential electric field is generated in the conductor, which provides for charges transfer and current in the conductor.

The described processes have an electrostatic nature and are accompanied by small losses in the conductor. If we take two capicators, one of them charged, and make a closed circuit, the conduction current in the closed circuit will create Joulean losses in conductors connecting the capiators.

However, if we connect a charged spherical capicators by a single conductor with an uncharged sphere, charges transfer from one sphere to another will not be accompanied by

Joulean losses. In this case, a circuit is opened and there are no conduction currents in there.

Surface charges in the single conductor waveguide change in time and create a displacement current in the environment around the conductor, which is closed by a current in the conductor excited by the potential coulomb electric field. It is known that

displacement currents, unlike conduction currents, are not accompanied by the generation of Joulean heat [12].

No heat is extracted during current flow through the conductor excited by the voltage of the coulomb electric field.

N. Tesla wrote that processes of electric power transfer in his resonance high-voltage systems have electrostatic nature and, due to creation of standing waves, have low losses.

In the USSR, revival of resonance technologies of electric power transmission began from works of an engineer of the Ail-Union Electrotechnical Institute in the name of V.I. Lenin (VEI) S.V. Avramenko. In the eighties of the XX century, he developed and patented single-wire electric systems with a power of 10 - 100 W and voltage of 1 - 100 kV. S.V.

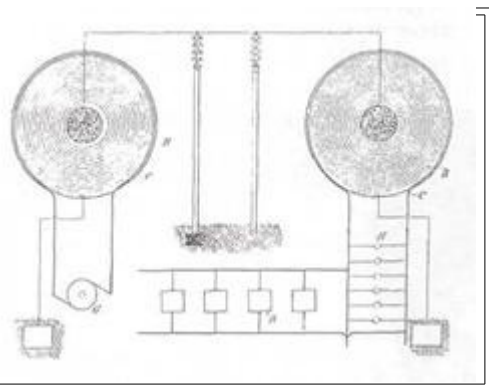


Fig. 3. Electric circuit of N. Tesla's device for resonance system of electric power transmission [9].

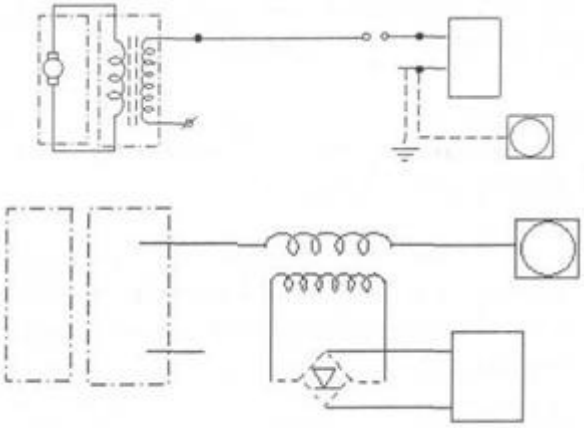
Avramenko used thyristor frequency converters of 1 - 30 Hertz and his own capacity of Tesla's step-up and step-down transformers in order to generate resonance. Since 1990, these works were developed in the All-Union Institute for Electrification of Agriculturale (VIESH), where S.V. Avramenko worked as an engineer (combining jobs) in the laboratory of electrical equipment use (the head of the laboratory was a candidate of technical science A.I. Nekrasov).

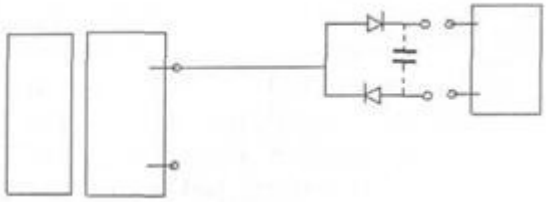
In his patents [3, 4], S.V. Avramenko referred to N. Tesla's works, however, that time he did not know Tesla's patent [9] for the single-wire system, thus, he practically invented and made it again (Fig. 3, 4). S.V. Avramenko wrote [13, 14]: "It is necessary to say that energy transmission using a single wire was demonstrated by Nicola Tesla as long ago as in 1894.

But no concrete information about the realization of this experiment is known". In fact, N. Tesla's patent [9] (Fig. 3) and numerous articles in [1], and also more than 300 pages containing the description of N. Tesla's experiments in his laboratory in Colorado-Springs [2] contain large volumes of data on the single-wire resonance system (RS) of electric power transmission developed by N. Tesla.

Fig. 4. Electric circuit of power supply of transmitting (a) and receiving (b) devices by Avramenko for resonance transfer of electric power [13]. {here and then

notations on figures are explained in the text)

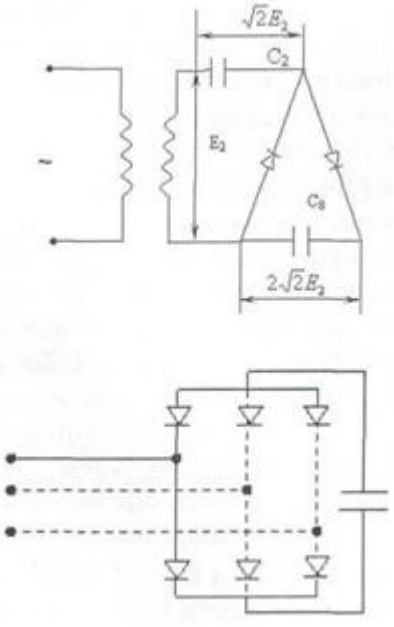




Obviously, at the time when S.V. Avramenko wrote his patents, he had no access to the works [1, 2, 9]. In order to rectify current and voltage in the one-wire line, S.V. Avramenko offered his famous "Avramenko plug", a diode-condenser block, which was unknown to Tesla because there were no diodes in XIX century. Still the "Avramenko plug" is a component of the known voltage-doubling circuit or monophase input of any bridge rectifier (Fig. 6).

Fig. 5. S.V. Avramenko's plug for current rectifying in the single-wire line [13]

Fig. 6. Circuit of voltage doubling (a) and circuit of monophase input of three-phase bridge rectifier (b).



Using properties of reactive cold plasma occurring as a result of the single-wire line's break, S.V. Avramenko developed and patented electro- plasma coagulator, which is successfully used in veterinary medicine, cosmetology and medicine [15, 16].

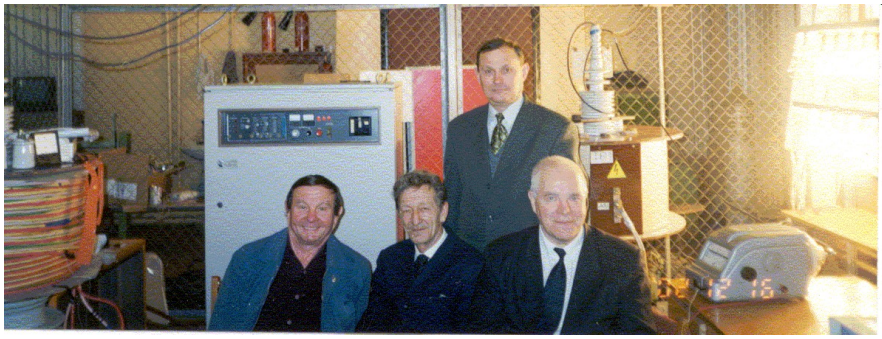
Our acquaintance with S.V. Avramenko began after his letter addressed to the secretary of the

Central Committee of the CPSU Egor Ligachev, where S.V. Avramenko suggested using his invention for the development of the electric power supply of remote customers in rural regions with small line losses. E. Ligachev's instruction to investigate and prepare suggestions was transferred to VIESH through the head of department of the Ministry of Agriculture M.P. Kharin. A commission of VIESH's academic council was formed. S.V. Avramenko gave a speech in front of the commission and demonstrated the work of a fan with a 5 W electric motor and a lamp using an electric power transmission over the single-wire line from the power circuit of 220 V, 50 Hertz. Scientists of VIESH approved S.V. Avramenko's work and suggested using the new method for the electric power supply of remote rural regions. S.V. Avramenko was invited to continue working on the resonance single-wire electric system in the VIESH department of electric power supply and the Academy of Agricultural Sciences assigned 100,000 roubles for the development of equipment and conducting of research. Using this money, transmitting and receiving blocks of the resonance electric system with power of 100 W and voltage of 10 kV were produced in VIESH with the assistance of S.V. Avramenko.

In the nineties, D.S. Strebkov was invited to N. Tesla's museum by a director of the Institute of Chemical Current Sources in Belgrade, Doctor Petar Rakin. With his financial support, D.S. Strebkov visited the museum and got three volumes of Tesla's works in English, which were prepared for publication by the museum, including [1, 2]. The study of N. Tesla's patents and articles helped to considerably hasten and develop works on resonance methods of electric power transfer made in VIESH.

Since the "umbrella" patent of S.V. Avramenko was obtained in the USA and other countries, we prepared the first patents of the Russian Federation for RS use in mobile energy engineering. VIESH has been developing electric tractors with cable power supply for many years, and we decided that the use of RS would allow decreasing the weight of the cable drum from 3 tones to 30 - 50 kg and improving the reliability of mobile aggregate's power supply.

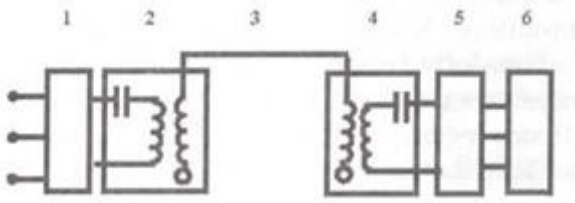
We have invited S.V. Avramenko as a co-author in all patents of the Russian Federation (more than 10 of patent applications were filed by VIESH) as he had been an initiator of RS in Russia.



On the 31st of March 2003, S.V. Avramenko unexpectedly died of stroke. He was a talented Russian electrical engineer and a propagandist of Tesla's works. S.V. Avramenko made much for the popularization of N. Tesla's ideas (Fig. 7).

Fig. 7. Testing of the resonance RS-20 in VIESH on the 16th of December 2002. From right to left: D.S. Strebkov, A.I. Nekrasov, S.V. Avramenko, O.A. Roschin.

He was an excellent electric engineer and, in his experiments, demonstrated the abilities of the single-wire electric system to transfer electric power with small losses over tungsten wire with a diameter of 10 micrometers. In the nineties, in VIESH, the testing of a single-wire line made of plastic fishing-line with a diameter of 1 mm covered by an aluminium film with thickness of 0.4 micrometers was carried out using the device of S.V. Avramenko with power of 100 W. Then, a quartz fiber-optic line with a diameter of 1 mm covered with an aluminium protective layer was tested as a single-wire line. After that, D.S. Strebkov suggested using layers of water, soil, oxide conductive films on the basis of oxides of indium and tin (ITO) on a glass surface as the single-wire lines. Successful experiments were conducted and patents of the Russian Federation were obtained. In 2000, D.S. Strebkov suggested using laser beams in the atmosphere and ionosphere in order to create a pipe in resonance system of electric power supply of aircrafts and the Earth. Afterwards he obtained a patent for the use of an electronic beam in order to transfer electric power in space and energy exchange between spacecrafts and earth with the help of counter-laser-electronic beams.



In 2001, VIESH accepted with thanks an offer of the deputy director general of "Surgutgazprom" company ES. Burganov to develop a prototype of RS with an electric power of 20 kW. At that time, VIESH had a prototype with a power of 100 W and it happened to be a rather serious problem to create a system with a power of 20 kW in a brief period of time. We had to completely change the design of the resonance transformers made by S.A. Avramenko and make the transformer's characteristics more similar to Tesla's transformers. We also had to develop new elements of the resonance circuit and their set up methods.

The operation principle of RS is based on the use of two resonance circuits with a frequency of 0.5 - 50 kilohertz and a single-wire line between the circuits (Fig. 8) with a line voltage of 1 - 1000 kilovolt during the resonance operation mode. Electric power transmission is carried out with the help of alternating electrostatic field, that is why Joulean losses in the line are minimal.

Fig. 8. Electric circuit of RS

1 - frequency converter; 2 - resonance circuit of step-up transformer; 3 - single-wire line;

4 - resonance circuit of step-down transformer; 5 - rectifier-inverter; 6 – load

Any conductor can be used as the single-wire waveguide, for example, a steel wire or any other conducting medium, which plays the role of s a guide of electric power flowing from the generator to the receiver.

In order to adjust a standard electric power supply system with the suggested one, matching devices and transformers are developed, which are set in the beginning and in the end of the single-wire line and allow using standard electrical equipment of direct and alternating current at the inlet and outlet.

An industrial 25 kW frequency converter, which was used by us for designing the new device, had water cooling. It was inconvenient for autonomous use. In order to obtain a three- phase network of 50 Hertz at the outlet of the system, design of a P-22 frequency converter was changed and improved and three monophase chokes for operation with a load module made of an incandescent lamp were produced. RS with a power of 20 kW was successfully tested in VIESH and at KS-5 object owned by "Surgutgazprom" company in Tumen region [17] (Fig. 9).

The testing results for RS-20 are given in Table 1.

The developed design solutions laid the foundation for production of resonance systems with a power of 100 - 1,000 kW.

Advantages and possible fields of application of RS are the following [18].

Fig. 9. Frequency converter and resonance circuit of transmitting high-voltage transformer with electrical power of 20 kW, 10 kV.

Table 1. Testing results of resonance system with electrical power of 20 kW

Electrical power with load, kW	20.52
Current, ampere	54
Voltage, V	380

Line voltage, kV		6.8
Line frequency, kilohertz		3.4
Line length	6 m	1,7 km
Diameter of line wire	0.08 mm	1 mm
Maximal effective current density by unit of square of line conductor's cross-cut, ampere/mm^2		600
Maximal specific electric output in single-wire line, MW/mm^2		

Scope of the use of resonance single-wire energy system

1. Electric power supply of agricultural and rural settlements.

2. Single-trolley and single-conductor cable hybrid electric-transport.

3. Fundamentally new single-electrode electrical devices and plasmatrons: electric cultivators, water and sewage disinfection, ozone production, veterinary plasma coagulators and scalpels.

Advantages of resonance method of electric power transmission

1. Electric power is transferred with the help of reactive capacitive current in the resonance mode. Unauthorized use of the energy is made difficult.

2. Aluminium and copper content in the wire can be reduced by 5 times.

3. Electric power losses are small in the single-wire line, and electric power can be transmitted for long distances.

4. Short circuits are impossible in the single- wire cable and it cannot cause fire.

In VIESH, the development of resonance methods of electric power transmission is being carried out by radio engineer A.N. Karamzin, electrical engineers A.I. Antonenko, V.V. Shemiakin, O.A. Roschin, L.Y. Yuferev, V.Z. Trubnikov, A.B. Sivtsov, G.S. Liapin, and V.I. Volosatov. Talented Russian scientists, candidates of technical sciences Zayev and V.I. Verutin are working on these problems. Doctor of technical sciences A.P. Korshunov and candidate of technical sciences V.N. Shabarov are developing technical and economic characteristics of RS.

President of the Russian Academy of Agricultural Sciences academician G.A. Romanenko, Corresponding Members of the Russian Academy of Sciences A.F. Dyakov and N.S. Lidorenko, a deputy minister of energy of the Russian Federation V.S.

Stanev and the head of technological progress department of Ministry of energy of Russia P.P. Bezrukih visited laboratory of VIESH and attended on RS testing. A deputy director general of "Surgutgasprom" company F.S.Byrganov, the deputy chief of energy department of "Gazprom" company O.A. Kuznetsov rendered assistance in production of the prototype RS-l0 kW.

In the laboratory of VIESH, a small pool is demonstrated, where fish live and a model of an electric river boat sails generating electric power from spring water (Fig. 10).

Electromagnetic waves in certain frequency range are poorly absorbed by seawater and soil and, therefore, can be used in the system of underwater and underground information transmission. Weakening of electromagnetic waves in sea water is [19]:

$$a.(f) = 0.00345\sqrt{f} \quad \text{decibel/m} \tag{3.8}$$

At a frequency of 100 Hertz attenuation at a sea depth of 300 m will be 90 decibel.

Our experiments show that not only electronic information but also electric power can be transferred over seawater and the ground. The resonance single-wire system of energy transmission has considerable advantages in comparison with the transmission of electromagnetic waves in air [20]. First of all, this is high efficiency of energy transmission (more than 85%) when using rather simple electrical equipment. High efficiency is conditioned by the presence of a resonance pipe between the generator and the receiver. The second important difference is connected with the resonance power station not needing to receive and transmit aerials. It is only necessary to provide for resonance in high-voltage and low-voltage of Tesla's transformer winding. This means that, for example, a submarine vessel can generate energy from water not lifting up any scanner assemblies.

The third important conclusion is that, in order to transmit energy, no air transmission facilities are needed. They are the main source of the disruption of service caused by ice-crusted ground, hurricanes, fires, and earthquakes. Future energy engineering will use reliable and safe underground and underwater single-wire cable lines and also seawater and the ground as the single-wire resonance line.

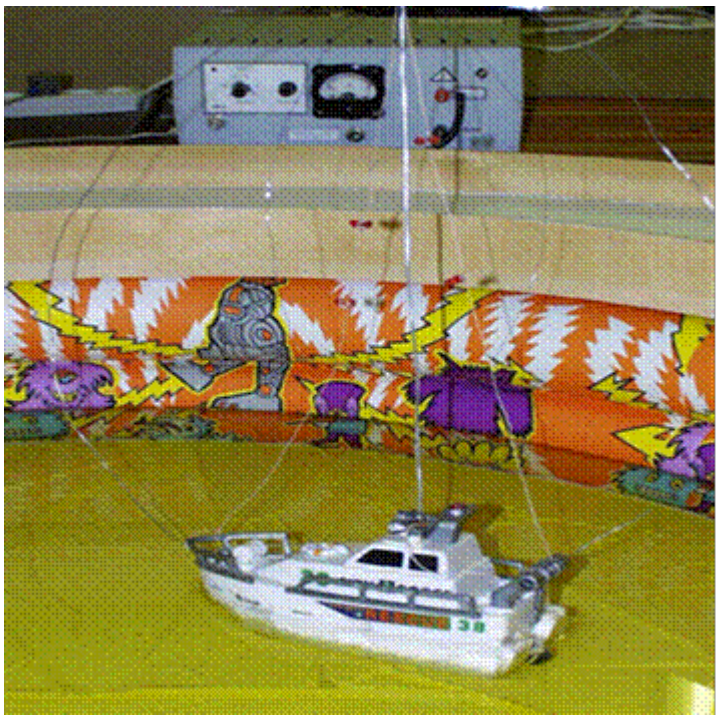
N. Tesla wrote: "Perhaps the most significant application of wireless energy engineering will be the power supply of aircrafts, which will move without fuel". [6]. Scientific ideas and patents stated in [18] allow beginning practical realization of no fuel aircrafts and making possible things, which could not be predicted by Tesla: to provide for resonance energy transmission over an electron beam between spacecrafts and, over counter laser,microwave and electronic beams, between the Earth and space objects.

N. Tesla believed that his resonance methods of electric power transmission will be widespread in the future. The same belief has been supporting us during our work. We will see what will change in the electric power engineering in one hundred years.

Our forecasts on the development and use of resonance waveguide methods of electric power transmission can be summarized as the following:

• Air transmission facilities will be substituted by underground waveguide systems.

• Electrical machines-robots with active labour bodies will operate at agricultural plantations.



• A global solar energy system generating electric power, hydrogen fuel and heat for every person on Earth will be created.

• Liquid fuel and gas will be generated from the biomass of agricultural plantations.

• Spacecrafts will be launched from Earth using electrical jet propulsion. They will have a ratio of payload mass to launching mass 80 - 90% instead of today's 5%.

• Power supply of aircrafts in space and transmission of electric power to mobile objects on Earth will be made by wireless methods

• Resonance methods will be used for medical treatment of people and animals, extermination of weeds (instead of pesticides), drinking water and waste disinfection, creation of new especially pure materials (first of all, solar silicon), and hydrogen production.

Fig. 10. Testing of the river boat model in VIESH's laboratory using tap water as the single- wire waveguide. The transmitting block has an electrical power of 100 W and a voltage of 1 kV.

The twentieth century was the last century of cheap energy. The age of cheap energy came to an end and new energy technologies are necessary to provide for sustainable future development. New energy technologies will not use fossil fuel. The global solar energy system [8] consisting of three 2,5 TW solar power plants 210 x 210km each located in Australia, Africa and North America will be able to provide for electric power, hydrogen fuel and heat all Earth's regions twenty-four hours a day for a million years and turn all electric power stations using fossil fuel into a class of emergency power plants. Maximal efficiency of solar cells achieved in laboratories is industry 20% and their practical tenure of employment is 50 years.

In order to make the global solar system operate, it is necessary to organize transcontinental teraW flow of electric power. Resonance technologies of electric power transmission can be used for creating the global energy system. Mankind will be able to unite and concentrate its energy reserves and technologies in order to create adequate living conditions for every person and realization of important scientific and technical projects on Earth and in space.

References

1. Tesla N. Lectures. Patents. Articles. Published by N. Tesla Museum. Beograd, 1956, 715 pp.

2. Nikola Tesla. Colorado Springs Notes 1899-1900. Published by Nolit. Beograd, 1978, 437 pp.

3. Malov N.N. Course of electrotechnology and radio engineering for teacher's training colleges. State Pedagogical Training Publishing House. M., 1938. p. 125.

4. Kalinin E.B. Research on overvoltage in electrical facilities. M., 1936. p. 65-66.

5. Alexandrov G.N., Smolovic S.V. Flexible lines for electric energy transmission over long distances // V Symposium "Electrical Engineering - 2010" (October 12- 22, 1999, Moscow region). P. 35-42.

6. Trinkans G. Tesla - The Lost Inventions. Vantage Press, 1988, 32 pp.

7. Electricity transmission of direct and alternating current of extrahigh voltage. Electrotechnical reference book. V. 3. M., 2002. P.196-197.

8. Strebkov D.S., Irodionov A.E. Global Solar Power System // Eurosun 2004. 14. Intern. Sonnen Forum, 20 - 23 June 2004, Frieburg, Germany. Val 3, PV systems and PV Cells. P. 3-336 - 3-343.

9. US Patent 593138. Electrical transformer / Tesla N. 02.11.1897.

10. Meinke H., Gundles F. Single wire as a waveguide system. Electrotechnical reference book. M. - L., 1960. V.1. p. 188.

11. Sotnikov V.V. Sources of coulomb field in conductors and their influence on electric current // Izvestiya AN. Energetika.2002.1. p. 104-111.

12. Tamm E.I. Fundamental theory of electricity. M. Nauka, 1976. p. 133, 397-400.

13. Patent of the Russian Federation 2108649. Method of power supply of electrical devices and device for its implementation / Avramenko S.V. // 1998. #41.

14. European Patent 639301. Apparatus and method for single - wire electrical transmission / Avramenko S.V. // European Patent Bulletin 97136. September 1997.

15. Patent of the Russian Federation 2100013. Device for tissue coagulation / Avramenko S.V., Stupin N. V. //1995. #36.

16. Strebkov D.S., Nekrasov A.I., Avramenko S.V., Avramenko K.S. Cold-plasma electric coagulator //Mechanization and electrification of agriculture. 2002.#2. p. 19-20.

17. Avramenko S.V., Burganov F.S., Nekrasov A.I., Roschin O.A., Strebkov D.S. Research on single-wire energy system with electric power of 20 kW // VII symposium "Electrotechnology - 2010". Perspective types of electrical equipment for transmission and distribution of electric energy. (27-29 of May 2003, Moscow region). Collection of reports. Volume 1.2.16. M., 2003, p. 163-169.

18. Strebkov D.S., Nekrasov A.I. Resonance methods of electric energy transmission. Publishing house of Russian Academy of Agricultural Science, M., 2004. p. 185.

19. Nefedov V.I. Fundamental radio electronics and connection. M. Vyshaya shkola. 2002, p. 17.

20. Didenko A.N. Microwave energy. Theory and practice. M.: Nauka, 2003, 446.