3D Modeling and Simulation of the Tesla's Polyphase Generators nad Motors

Vladan Vučković

Abstract - This paper presents the 3-D modeling and simulation of the Tesla's poly-phase generators and machine using original real-time simulator. Models and simulations of Tesla's alternating current generators and induction motors based on his rotating magnetic field are presented. Power transformers and rotating magnetic field that is invented by Tesla is the basic concept of his poly-phase system for producing, transferring and utilization of the alternating electric energy.

Keywords - 3d modeling and simulation, rotating magnetic field, Tesla's induction motor.

I. INTRODUCTION

Project *Computer Simulation and 3-D Modeling of the Original Patents of Nikola Tesla* started in April 2009 in cooperation with the Faculty of Electronics in Niš and a Nikola Tesla Museum form Belgrade. The aim of the project realized by the Faculty of Electronic Engineering in Niš is multiple. Basically, it deals with detailed 3-D modeling [1],[2] of the original patents of Nikola Tesla, which are the part of the Museum's archives. Using 3-D models, further objectives are rendering, animation, simulation and visualization of the different machines in real time. One of the basic intentions is to simulate some of the fundamental Tesla's invention in the field of power generating and utilization using alternating currents. The main invention in Tesla's poly-phase system is his invention of the *rotating magnetic field*. This invention enables the realization of the induction motors without commutators - feature that is very useful for industry. Nikola Tesla invented this in 1882, in a moment of inspiration. A few years later, he patented basic concepts of his new poly-phase system in US.

This paper presents basic details about the 3d modeling, simulation and realization of the models of Tesla's generators and motors using the concept of the rotating magnetic field in improved version of author's original particle simulator. The user is able to monitor these machines in real time and tune some parameters of the alternating currents in stators. Also, we simulate the complete work of the tree-phase generators and induction motors with the original 3D engine. Simulator could visualize the movements of the rotor in induction motor as well as magnetic field itself near the engine model.

Vladan Vučković is with the Department of Computers, Faculty of Electronic Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia and Montenegro, E-mail: vladan.vuckovic@elfak.ni.ac.rs.

II. THE IDEA OF ROTATING MAGNETIC FIELD

The invention of the rotating magnetic field in terms of practical and industrial use is the work of Nikola Tesla [3],[4]. The Italian electrical engineer Galileo Ferraris accidentally stumbled on the effect of rotation in the field with two spools and current difference of 90 degrees, but not found the right value effect. Tesla is exhibited in his autobiography that he found a rotating field in early 1882. In 1888, Tesla was awarded US patent (US Patent 381.968) for his invention. From the first concept of rotating fields there was a series of practical inventions of the early types of motors and generators, which were later found their application in industry [4]. The Tesla fundamental patents are presented in following diagrams (Fig.1).

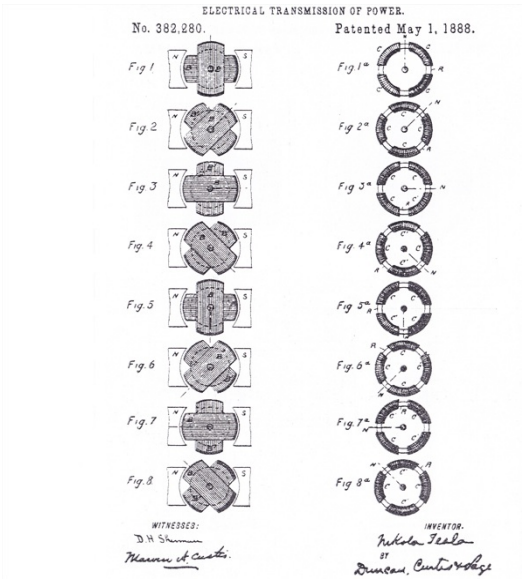


Fig.1. Fundamental concept of rotating magnetic field (US patent 382.280).

In Fig.1. Tesla described all key positions of rotor into the rotating magnetic field motor. To achieve rotating

someone does not need to use commutators or other switch devices. Through this patent Tesla postulated a basic principle for transmission of the electrical energy using the alternating poly-phase currents. The first poly-phase engine and the concept of the first motor that Tesla has built as the practical demonstration of his invention is based on this patent. The generator uses the rotating permanent electro magnet producing alternating currents with different phases. The presented motor uses alternating current with phase difference of 90 degrees, energizing two different poles of it. The stator has common iron core and four electro-magnets. The rotor is simple and is made of iron or some other ferromagnetic material. *There is no commutator*. These phase-differenced currents generate rotating magnetic field in stator that moves the rotor. This is also asynchronous machine; the speed of rotation is similar but under the virtual speed of the rotating field.

Studying these engines, we can observe that the magnetic flux is placed around the stator in near proximity of the machine. The inner space (rotor) is also under magnetic influence of the stator, so rotating magnetic field is driving (hanging) the rotor in fact.

The next scheme (Fig.2.) presents the poly-phase alternator (generator). This machine is able to generate two phase currents in two separate circuits. The stator is constructed with eight groups of inductors and the rotor has two electro or permanent magnets. In Tesla system, inductors are connected in stator part of machine. The rotation of the magnets generates two phase alternating current.

The other conception of this generator is also presented. In this case, the rotor is in the constant magnetic field generated by the permanent magnet in stator. The rotation of the inductions in the center of the machine generates two alternating currents with the phase difference of 90 degrees.

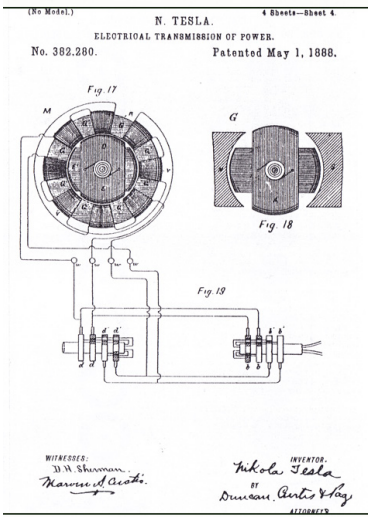

(No Model.) 4 Sheets—Sheet 4.
N. TESLA.
ELECTRICAL TRANSMISSION OF POWER.
No. 382,280. Patented May 1, 1888.
Fig. 17
Fig. 18
Fig. 19
WITNESSES:
INVENTOR.
Nikola Tesla
BY
ATTORNEYS.

Fig.2. Original Tesla's U.S. patent 382.280; alternator for two-phase currents.

Now, these currents could drive the two phase rotating magnetic field engine that is earlier presented. We could notice here Tesla's conception is general. He invented not only the principle of the rotating magnetic field but also the generators (alternators), the principle of using poly-phase transformers and different kinds of the motors based on same principle. The simplest variation oh Tesla's system is two-phase system, but the same idea could be realized with three or more phases. Nowadays, the modern Tesla system is commonly three-phase, including alternators, transformers and induction motors. This variant of the Tesla's system is proved as optimal and it is widely used for more of 100 years.

III. MODELING THE MOTORS AND GENERATORS

On the basis of Tesla's patents, we have developed a 3D model first, and then the simulation of engine [5]. We use standard tools like Autodesk 3dsMax and Maya, with the programmed action of the 3D force field vector.

In the first phase, we constructed wire models [6]. We developed some complex models of different Tesla machines: generators, motors and transormers (Fig 3a-c).

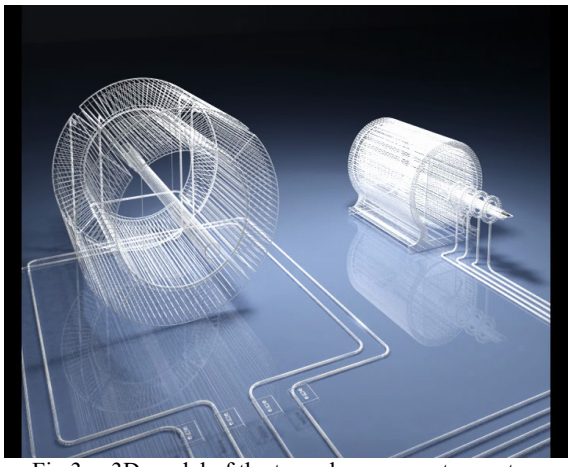


Fig.3a. 3D model of the two-phase generator-motor.

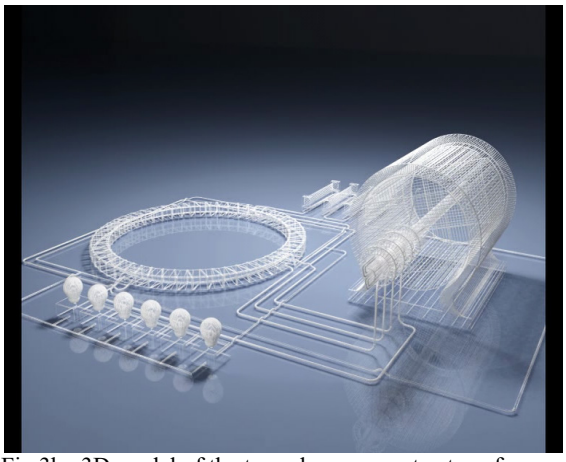


Fig.3b 3D model of the two-phase generator-transformer.

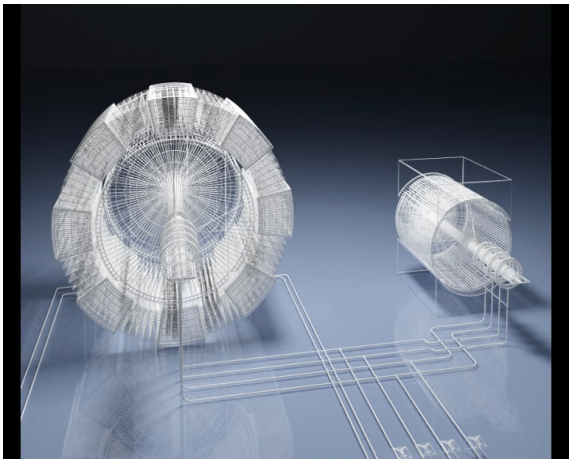
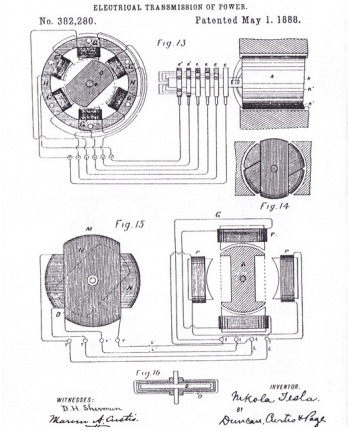


Fig.3c. 3D model of the three-phase generator-motor.

The stators and the rotors are clearly separated in all motors. Rotors are provided for rotation around the central axis. In transformer models, the lights are connected to motors. In the next phase the materialization taking into account the metal magnetic pieces and copper conductors. In the end, we merged the generator and motor conductors in the model, following the patent applications (Fig.4.).


ELECTRICAL TRANSMISSION OF POWER.

No. 382,280. Patented May 1, 1888.

Fig. 13

Fig. 14

Fig. 15

Fig. 16

WITNESSES: D. H. Shumway, Marcus A. Curtis.

INVENTOR: Nikola Tesla, BY Duncan Curtis & Page

Fig.4. Tesla patent of induction generator-motor system with wiring.

The correspondent 3D model is presented in Fig.5a.b.

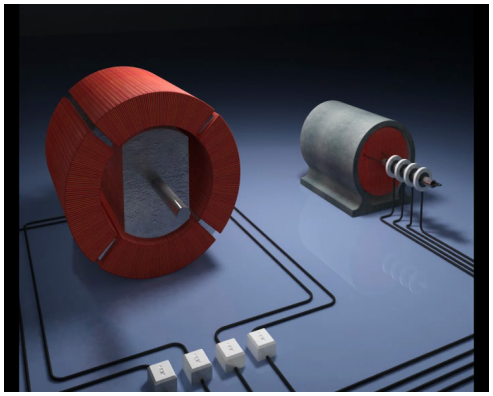


Fig.5a. Two-phase induction motor-generator 3D model.

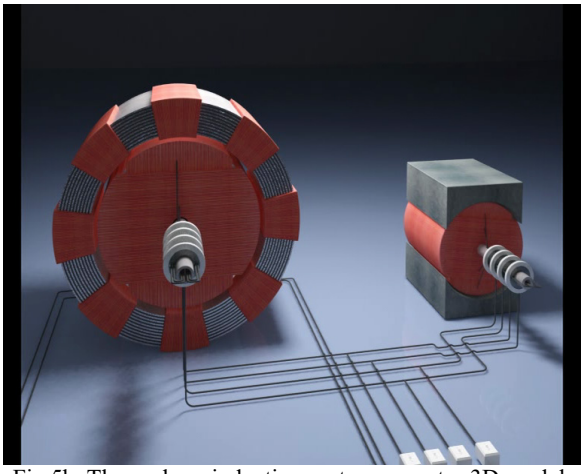


Fig.5b. Three-phase induction motor-generator 3D model.

An important model to simulate was Tesla symetric motor-generator. There are two identical machines symetricly connected. One machine could act like generator and the other like motor and vice-versa (Fig. 6.a.b.).

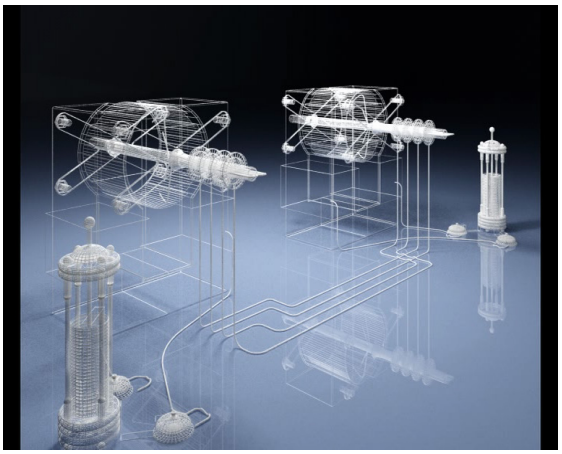


Fig.6a. Two phase symmetric induction motor-generator 3D wire model.

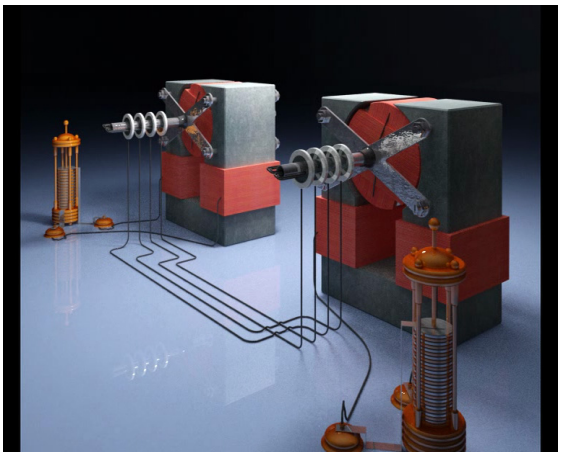


Fig.6b. Two phase symmetric induction motor-generator 3D model.

There is no limitation to implement this procedure. We realized and presented tens of Tesla's models.

IV. SIMULATION

After the preliminary phases we have complete generator-motor model. Model must follow the basic functionality of the Tesla's patent, so we must define the rotation of the alternating generator, the transmission and rotation of the induction generators and motors. In the next figure (Fig.7.) we presented simulation of 2-phase alternator-motor.

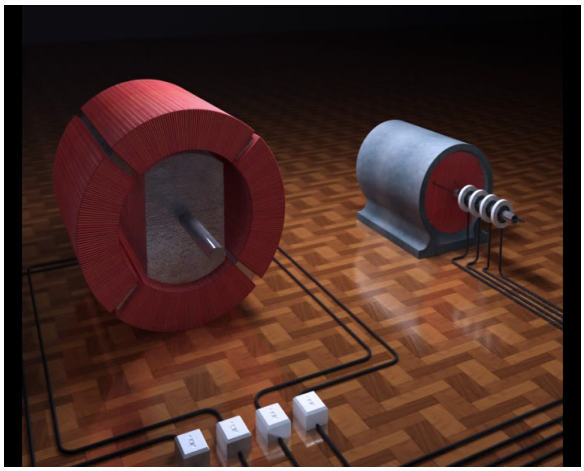


Fig.7. Simulation of two-phase alternator-motor system.

This model is actually correspondent with the schematic version in Tesla's patent, consisting of permanent magnetic rotor, iron stator and eight copper inductions. The materials are also carefully chosen having in mind the functionality of this device [7]. Rotation speed is also controlled in simulation. Alternator produces alternating currents developing the rotating magnetic field in motor (Fig. 8).

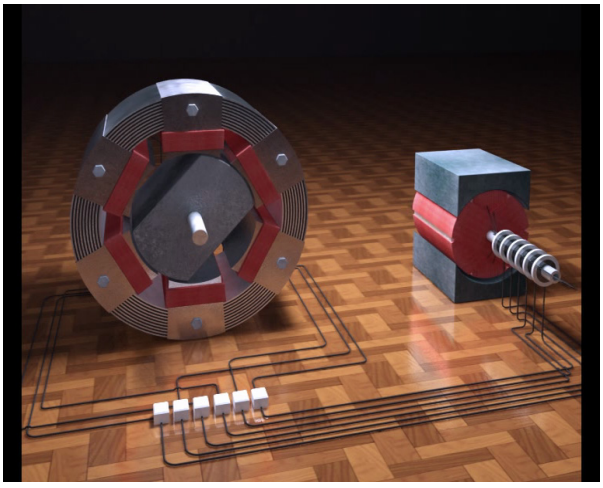


Fig.8. Simulation of three-phase alternator-motor system.

We also use proper wiring to support the total functionality of the model. Of course, the modeling of the current flow in conductors is very complex and it is not needed in this work, but on higher level we also use the current modeling, separately in all wires. The virtual currents are in function of phase of alternator.

In the next figure (Fig.9) the wiring in model is presented. All of these wires are under different virtual voltage, so system performs the simulation on this level. When start to rotate the generator, the model follows the currents and then it generates the virtual rotating magnetic field that is presented visually in model.

The change of the rotation direction in alternator generates the different virtual currents in opposite rotation of the rotor in motor, with time delay.

In alternator-transformer-lights simulation, alternator generates two-phase currents through transformer and then fires the lights (Fig. 9).

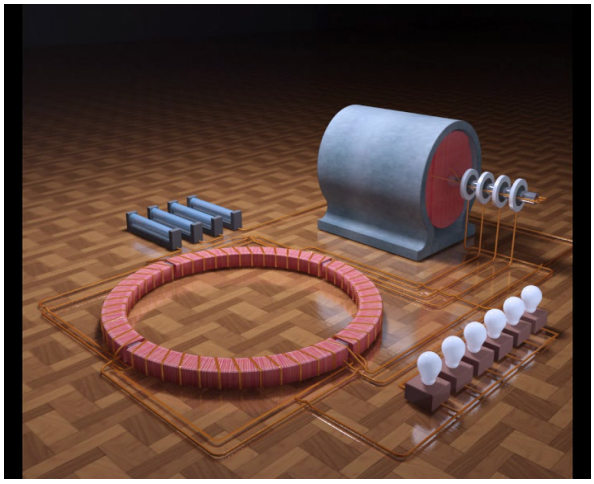


Fig.9. Alternator-transformer simulation.

V. REALIZATION

Generally, simulation of the processes is realized through the standard 3D environment.

In the special cases, like quantum or field effect Delphi 7 programming environment could be used for manual programming.

We use classical approach and first define data record as the array of quantum information:

```
...
type_elec = record
        x,y:real;     {x and y coordinates}
        vx,vy:real;   {Real velocity}
        q,m:real;     {Mass and electric charge}
        {.}
        newx,newy:integer;   {New video coordinates}
        oldx,oldy:integer;   {Old video coordinates}
```

```
          {.}
          mass:integer;
          {.}
         end;

var T: array [1..num] of type_elec;  {main array}
...
```

For instance, the main simulator line used in our system could be defined in this procedure:

```
procedure SIMULATOR_LINE(Sender: TObject);
begin

 stoping:=false;

 REPEAT
   {.}
   GENERATOR;
   {.}
   ELECTROt;   {Electrostatic field influence}
   MAGNETt;  {Magnetic field influence}
   {.}
   LIMITt;  {Space limits}
   {.}
   MOVEt;   {Move particles}
   TRANSt;  {Change physical coordinates}
   VIEWt;   {View}
   {.}
   application.ProcessMessages;
   {.}
 UNTIL stoping;

end;
```

The next listings define 3 main procedures in our simulator:

```
{-------------------------------------------------}
{Electrostatic field influence}
{-------------------------------------------------}

procedure ELECTROt;
var deltavx,deltavy:real;
begin
   for i:=1 to num do
   begin
      {deltavx:=t[i].q*EX*deltat/t[i].m;}
      deltavy:=t[i].q*(EY+ESTAT)*deltat/t[i].m;
      {.}
      {t[i].vx:=t[i].vx+deltavx;}
      t[i].vy:=t[i].vy+deltavy;
   end;

end;

{-------------------------------------------------}
{Magnetic field influence}
{-------------------------------------------------}

procedure MAGNETt;
var deltavx,deltavy:real;
begin
   for i:=1 to num do
   begin
      deltavx:=t[i].q*BB*t[i].vy/t[i].m;
      {deltavy:=t[i].q*BB*t[i].vx/t[i].m;}
      {.}
      t[i].vx:=t[i].vx+deltavx;
      {t[i].vy:=t[i].vy+deltavy;}
   end;
end;

{-------------------------------------------------}
{Moving the particles}
{-------------------------------------------------}

procedure MOVEt;
var realx,realy,dsr:real;
begin
   for i:=1 to num do
   begin
      realx:=t[i].vx*deltat;
      realy:=t[i].vy*deltat;
      {.}
      t[i].x:=t[i].x + realx;          {move x}
      t[i].y:=t[i].y + realy;          {move y}
      {.}
      {.}
{x levo}  if (t[i].x<1) then begin t[i].x:=maxx-1; end;
{x desno} if (t[i].x>maxx) then begin t[i].x:=1; end;
        {.}
{y levo}  {if (t[i].y<1) then begin t[i].y:=maxy-1; end;
{y desno} {if (t[i].y>maxy) then begin t[i].y:=1; end;}
        {.}
{y}       if (t[i].y<=1) then begin t[i].vy:=-(t[i].vy/3);
t[i].y:=t[i].y - realy; end;
{y}       if (t[i].y>=maxy-1) then
                  begin
                    t[i].vy:=-(t[i].vy/3);
                    t[i].y:=t[i].y - realy;
                    {.}
                    dsr:=random(down_speed_reductionn);
                    {.}
                    dsr:=dsr+1;
```

```
            {.}
            t[i].vx:=t[i].vx/dsr;
          end;
      {.}
  end;
end;
```

The basic idea is to use a step-by-step simulator. All particles in a field are subject to the effects of electrostatic and magnetic forces and their speed depending of these forces. In each cycle simulator done to change the position by the action of a force that can be controlled by special controls.
In this way the simulator works in real-time.

V. CONCLUSION

This paper presents the complete procedure of generating 3D models and simulations of different types of Tesla's generators and engines.

The first phase is the study of the basic patents of Nikola Tesla in connection with generators and motor based on the principle of rotating magnetic field [7],[8]. In the next phase, we started the materialization of a model adding the basic functionality of generator and engine. The models of generator-motor system are running in accordance with Tesla's patent application. The next phase is materialization of the 3d models of machines using appropriate software and information about the materials.

In this way we were able to simulate the work of the generator-motor systems as well other Tesla's machines. Over 30 models has been already realized according the project.

ACKNOWLEDGEMENT

The work presented here was supported by the Serbian Ministry of Education and Science (project III44006).

REFERENCES

[1] M. M. Woolfson, *Introduction to Computer Simulation*, OUP Oxford , ISBN-10: 019850425X

[2] Hartmann Alexander *Practical Guide to Computer Simulations,* World Scientific Publishing; Pap/Cdr edition, ISBN-10: 981283415X, 2009.

[3] E.L. Owen, "The induction motor's historical past". *IEEE Potentials* 7 (3): 27–30. doi:10.1109/45.9969., 1988.

[4] C. Mackechnie Jarvis (1970). "Nikola Tesla and the induction motor". *Phys Educ* 5: 280–7. doi:10.1088/0031-9120/5/5/306., 1970.

[5] Vladan Vučković "Simulation of the Three-phase Rotating Magnetic Field and Induction Engine" 12th international Conference on Applied Electromagnetics (PES 2015) ISSN 978-86-6125-145-0, Faculty of Electronic Engineering (FEE), University of Niš, Serbia, http://pes2015.elfak.rs , o5-1.1,o5-4, from 31.8.2015-2.9.2015,Nis,Serbia,2015.

[6] Владан Вучковић, "Virtual Models of Tesla Patents", *Зборник радова са XVII Телекомуникационог форума* ТЕЛФОР 2009, CD ROM Proceedings, Београд, 24-26. (ISBN 978-86-7466-337-0) str. 1335-1338, 2009.

[7] Vladan Vučković, Sanja Spasić "3-D STEREOSCOPIC MODELING OF THE TESLA'S LONG ISLAND" The Scientific Journal Facta Universitatis, Series Electronic and Energetics, no. 1,vol. 29, *http://casopisi.junis.ni.ac.rs/index.php/FUElectEnerg*, pp. 113-126 University of Nis, Serbia, 2015/2016, (DOI 10.2298/FUEE1601113V) (ISSN 0353-3670)

[8] V. Vučković, S. Spasić "Stereoscopic Modeling and Animation of the Tesla's Long Island Lab" XI International SAUM 2012 (Systems, Automatic Control and Measurements) Conference, 14.-16.11.2012. University of Nis, Faculty of Electronic Engineering, Nis.