Unipolar Induction in the Concept of the Scalar-Vector Potential

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Abstract

The unipolar induction was discovered still Faraday almost 200 years ago, but in the classical electrodynamics of final answer to that as and why work some constructions of unipolar generators, there is no up to now. Let us show that the concrete answers to all these questions can be obtained within the framework the concept of scalar-vector potential. This concept, obtained from the symmetrical laws of induction, assumes the dependence of the scalar potential of charge and pour on it from the charge rate. The symmetrization of the equations of induction is achieved by the way of their record with the use by substantial derivative. Different the schematics of unipolar generators are given and is examined their operating principle within the framework of the concept of scalar- vector potential.

Index terms— laws of induction, scalar-vector potential, unipolar induction, unipolar generators, substantial derivative.

1 I. Introduction

he unipolar induction was discovered still By faradeem almost 200 years ago [1], but in the classical electrodynamics of final answer to that as and why work some constructions of unipolar generators, there is no up to now. Is separately incomprehensible the case, when there is a revolving magnetized conducting cylinder, during motion of which between the fixed contacts, connected to its axis and generatrix, appears emf. Is still more incomprehensible the case, when together with the cylindrical magnet revolves the conducting disk, which does not have galvanic contact with the magnet, but fixed contacts are connected to the axis of disk and its generatrix. In some sources it is indicated that the answer can be obtained within the framework special relativity (SR), but there are no concrete references, as precisely SR explain the cases indicated. Let us show that the concrete answers to all these questions can be obtained within the framework the concept of scalar-vector potential. This concept, obtained from the symmetrical laws of induction, assumes the dependence of the scalar potential of charge and pour on it from the charge rate.

2 II. Concept of Scalar-Vector Potential

The Maxwell equations do not give the possibility to write down fields in the moving coordinate systems, if fields in the fixed system are known [2]. This Author ?: e-mail: mende_fedor@mail.ru however, these conversions from the classical electrodynamics they do not follow. Question does arise, is it possible with the aid of the classical electrodynamics to obtain conversions fields on upon transfer of one inertial system to another, and if yes, then, as must appear the equations of such conversions. Indications of this are located already in the law of the Faraday induction. Let us write down Faraday:B d E d l d t ? ? ? = ? ? ? ? ? ? . (2.1)

As is evident in contrast to Maxwell equations in it not particular and substantive (complete) time derivative is used.

The substantional derivative in relationship (2.1) indicates the independence of the eventual result of appearance emf in the outline from the method of changing the flow, i.e. flow can change both due to the local time derivative of the induction of and because the system, in which is measured , it moves in the threedimensional changing field . The value of magnetic flux in relationship (2.1) is determined from the relationshipB B d S? ? = ? ? ? , **(2.2)** where the magnetic induction B H µ = ? ? is determined in the fixed coordinate system, and the element d S? ? is determined in the moving system. Taking into account (2.2), we obtain from (2.1)d E d l B d S d t ? ? ? = ? ? ? ? ? ? ? ? ? ,**(2.3)**

and further, since d v grad d t t ? ? = + ? , let us write down [3-6] B E d l d S B v d l v d i v B d S t ? ? ? ? ? ? ? ? = ? ? × ? . (**2**E E v B ? ? ? = + × ? ? ? ? ? ? ? . (2.5)

If both parts of equation (2.6) are multiplied by the charge, then we will obtain relationship for the Lorentz forceL F e E e v B ? ? ? = + × ? ? ? ? ? ? ? . (2.6)

Thus, Lorentz force is the direct consequence of the law of magnetoelectric induction.

For explaining physical nature of the appearance of last term in relationship (2.5) let us write down B

3 ?

and E ? through the magnetic vector potentialB A ? : , B B A B rot A E t ? ? = = ? ? ? ? ? . (**2.7)**

Then relationship (2.5) can be rewrittenB B A E v rot A t ? ? ? ? ? = ? + × ? ? ? ? ? ? (2.8)

and further ( ) ( )B B B A E v A grad v A t ? ? ? = ? ? ? + ? ? ? ? ? ? (2.9)

The first two members of the right side of equality (2.9) can be gathered into the total derivative of vector potential on the time, namely:( ) B B d A E grad v A d t ? = ? + ? ? ? ? . (2.10)

From relationship (2.9) it is evident that the field strength, and consequently also the force, which acts on the charge, consists of three parts.

First term is obliged by local time derivative. The sense of second term of the right side of relationship (2.9) is also intelligible. It is connected with a change in the vector potential, but already because charge moves in the three-dimensional changing field of this potential. Other nature of last term of the right side of relationship **??**2.9) Let us write down the amount of Lorentz force in the terms of the magnetic vector potential:

(2.12) Is more preferable, since the possibility to understand the complete structure of this force gives.

Faraday law (2.2) is called the law of electromagnetic induction, however this is terminological error. This law should be called the law of magnetoelectric induction, since the appearance of electrical fields on by a change in the magnetic caused fields on.

However, in the classical electrodynamics there is no law of magnetoelectric induction, which would show, how a change in the electrical fields on, or motion in them, it leads to the appearance of magnetic fields on. The development of classical electrodynamics followed along another way. Ampere law was first introduced:H d l I = ? ? ? ? , (**2.13)**

where I is current, which crosses the area, included by the outline of integration. In the differential form relationship (2.13) takes the form: If we in relationship (2.16) use the substantional derivative, as we made during the writing of the Faraday law, then we will obtain [1][2][3] **??**4][5][6][7][8][9][10]:rot H j ? = ? ? , (**2**[ ] ( ) ( ) L B B B F e E e v ro tA e E ? v A ?grad v A ? = + × = ? ? + ? ? ? ? ? ? ? ? ? ? D rot H j t ? ? ? = + ? ? ? . (**2**[ ] D H d l d S D v d l v d i v D d S t ? ? ? ? ? ? = + × + ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? .

(2.17) In contrast to the magnetic fields, when0 divB = ?

, for the electrical fields on divD ? = ? and last term in the right side of relationship (2.8) it gives the conduction current of and from relationship (2.7) the Ampere law immediately follows. In the case of the absence of conduction current from relationship (2.17) the equality follows:[ ] H H v D ? = ? × ? ? ? ? . (**2**

4 .18)

As shown in the work [2], from relationship (2.18) follows and Bio-Savara law, if for enumerating the magnetic fields on to take the electric fields of the moving charges. In this case the last member of the right side of relationship (2.17) can be simply omitted, and the laws of induction acquire the completely symmetrical form [6] B E dl ds v B dl H t D H dl ds v D dl H t ? ? ? ? ? ? = ? + × ? ? ? ? ? ? ? ? ? ? ? ? ? ? = ? × ? , (2.19) or B rotE rot v B t D rotH rot v D dt ? ? ? ? = ? + × ? ? ? ? ? ? ? = ? × ? ? ? ? ? ? ? ? ? ? ? . (**2**

5 .20)

For dc fields on these relationships they take the form: If we in parallel to the axis of rod in the field E begin to move with the speed v ? another IS, then in it will appear the additional magnetic fieldE v B H v D ? ? ? = × ? ? ? ? ? = ? × ? ? ? ? ? ? ? ? ? . (**2**H E v ? ? = ? . If

we now with respect to already moving IS begin to move third frame of reference with the speed v ? , then already due to the motion in the field H ? will appear additive to the electric field( ) 2 E E v µ? ? = ?

. This process can be continued and further, as a result of which can be obtained the number, which gives the value of the electric field( ) E r v ?

in moving IS with reaching of the speed v n v = ? , when 0 v ? ? , and n?? . In the final analysis in moving IS the value of dynamic electric field will prove to be more than in the initial and to be determined by the relationship [7]:( ) , 2 v gch v c E r v Ech r c ?? ? ? ? ? = = .

If speech goes about the electric field of the single charge e , then its electric field will be determined by the relationship:( ) 2 , 4 v ech c E r v r ?? ? ? ? =

, where v ? is normal component of charge rate to the vector, which connects the moving charge and observation point.

Expression for the scalar potential, created by the moving charge, for this case will be written down as follows:(,) ( ) 4 v ech v c r v r ch r c ? ? ?? ? ? ? ? = = , (**2.22**)

where ( ) r ? is scalar potential of fixed charge. The potential(,) r v ? ? ?

can be named scalar-vector, since it depends not only on the absolute value of charge, but also on speed and direction of its motion with respect to the observation point. Maximum value this potential has in the direction normal to the motion of charge itself. Moreover, if charge rate changes, which is connected with its acceleration, then can be calculated the electric fields, induced by the accelerated charge.

During the motion in the magnetic field, using the already examined method, we obtain:( ) v H v Hch c ? ? ? = .

where v ? is speed normal to the direction of the magnetic field.

If we apply the obtained results to the electromagnetic wave and to designate components fields on parallel speeds IS as E ? , H ? , and E ? , H ? as components normal to it, then with the conversion fields on components, parallel to speed will not change, but components, normal to the direction of speed are converted according to the rule , 1

,v v v E E ch v B sh c c c v v B B ch v E sh c vc c ? ? ? ? ? ? ? = + × ? = ? × ? ? ? ? ? ? ? ? ? (2.23)

where c is speed of light.

Conversions fields (2.23) they were for the first time obtained in the work [8].2 2 0 0 0 1 0 0 1 0 0 1/ 0 0 1/ 0 0 0 y z y z E E U AU v U B c B c ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? = ? = ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

If one assumes that the speed of system is summarized for the classical law of addition of velocities, i.e. the speed of final IS

6 N K K ?=

relative to the initial system K is v N v = ? , then we will obtain the matrix system of the differential equations of However, the iteration technique, utilized for obtaining the given relationships, it is not possible to consider strict, since its convergence is not explained Let us give a stricter conclusion in the matrix form [7].( ) ( ) dU v AU v dv = , (**2**

Let us examine the totality IS of such, that IS K 1 moves with the speed v ? relative to IS K, IS K 2 moves with the same speed v ? relative to K 1 , etc. If the module of the speed v ? is small (in comparison with the speed of light c), then for the transverse components fields on in IS K 1, K 2 ,?. we have:2 1 1 2 2 1 1 2 1 1 / / E E v B B B v E c E E v B B B v E c ? ? ? ? ? ? ? ? ? ? ? ? = + ? × = ? ? × = + ? × = ? ? × ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ?

(2.24) Upon transfer to each following IS of field are here U is matrix column fields on in the system K , and U ? is matrix column fields on in the system K? .obtained increases in E ? ? and B ? ? 2 , / E v B B v E c ? ? ? = ? × ? = ?? × ? ? ? ? ? ? ? , (**2**

Substituting (2.28) into system (2.27), we are convinced, that U ? is actually the solution of system (2.27):[ ] exp( ) ( ) exp( ) ( ) d vA dU v U A vA U AU v dv dv = = = .

It remains to find this exponential curve by its expansion in the series:2 2 3 3 4 4 1 1 1 exp( ) ... 2! 3! 4! va E vA v A v A v A = + + + + +

where E is unit matrix with the size 4 4

× . For this it is convenient to write down the matrix A in the unit type form2 0 0 1 0 0 , , 0 . / 0 1 0 0 0 A c ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? ? = = = ? ? ? ? ? ? ? ? ? ? ? ? ? then 2 2 2 2 / 0 0 / c A c ? ? ? ? ? ? ? = ? ? ? ? ? , 3**2**3 4 0 / 3 / 0 c A c ? ? ? ? ? ? ? = ? ? ? ? ? , 4 4 4 4 / 0 4 0 / c A c ? ? ? ? ? ? ? = ? ? ? ? , 5**4**5 6 0 / 5 / 0 c A c ? ? ? ? ? ? ? ? = ? ? ? ? ? ?..

And the elements of matrix exponential curve take the form where I is the unit matrix 2 2 × . It is not difficult to see that [ ] [ ] 2 4 2 4 11 22 exp( ) exp( ) ...., 2! 4! v v vA vA I c c = = ? + ? [ ] [ ]( ) ( ) / / exp( ) / / / / 0 0 / 0 / / 0 0 / / / 0 / / 0 0 / Ich v c c sh v c vA sh v c c Ich v c ch v c csh v c ch v c csh v c ch v c c ch v c sh v c c ch v c ? ? ? ? ? ? ? = = ? y y z z z y z y y y z z E E ch v c cB sh v c E E ch v c cB sh v c B B ch v c E c sh v c B B ch v c E c sh v c ? ? = ? = + ? ? = + = ? or in the vector record , 1 , v v v E E ch v B sh c c c v v B B ch v E sh c vc c ? ? ? ? ? ? ? = + × ? = ? × ? ? ? ? ? ? ? ? (2.29)

This is conversions (2.23).

7 III.

8 Unipolar Induction in the Concept of the Scalar-Vector Potential

Let us examine the case, when there is a single long conductor, along which flows the current. We will as before consider that in the conductor is a system of the mutually inserted charges of the positive lattice g + and free electrons g ? , which in the absence current neutralize each other (Fig. 1).

The electric field, created by rigid lattice depending on the distance r from the center of the conductor, that is located along the axis z it takes the We will consider that the direction of the vector of electric field coincides with the direction r . If electronic flux moves with the speed, then the electric field of this flow is determined by the equality2 1 1 2 1 1 2 2 2 v v g g E ch r c r c ?? ?? ? ? ? ? ? ? = ? ? ? + ? ? ? ?.

(3.2) Adding (3.1) (3.2), we obtain:2 1 2 4 g v E c r ?? ? ? = ?

. This means that around the conductor with the current is an electric field, which corresponds to the negative charge of conductor. However, this field has insignificant value, since in the real conductors. This field can be discovered only with the current densities, which can be achieved in the superconductors, which is experimentally confirmed in works.2 2 1 1 2 2 g v E r c ?? + + ? ? = + ? ? ? ? , **(3.3)**2 1 2 ( ) 1 1 2 2 v v g E r c ?? ? ? ? ? ? = ? + ? ? ? ? . (3.4) z r 1 g + 1 g - 1 v v

Fig. **??** : Moving conductor with the current .Adding (3.3) and (3.4), we obtain:2 1 1 2 2 1 2 2 v v v g E r c c ?? + ? ? = ? ? ? ? ? . **(3.5)**

In this relationship as the specific charge is undertaken its absolute value. since the speed of the mechanical motion of conductor is considerably more than the drift velocity of electrons, the second term in the brackets can be disregarded. In this case from (3.5) we obtain Let us examine the case, when very section of the conductor, on which with the speed 1 v flow the electrons, moves in the opposite direction with speed v (Fig. **??**). In this case relationships (3.1) and (3.2) will take the form1 2 gv v g c + =

.

If we conductor roll up into the ring and to revolve it then so that the linear speed of its parts would be equal v , then around this ring will appear the electric field, which corresponds to the presence on the ring of the specific charge indicated. But this means that the consists. During the motion of linear conductor with the current the electric field will be observed with respect to the fixed observer, but if observer will move together with the conductor, then such fields will be absent.

As is obtained the unipolar induction, with which on the fixed contacts a potential difference is obtained, it is easy to understand from Fig. 3. We will consider that 1 r and 2 r of the coordinate of the points of contact of the tangency of the contacts, which slide along the edges of the metallic plate, which moves with the same speed as the conductor, along which flows the current. Contacts are connected to the voltmeter, which is also fixed. Then, it is possible to calculate a potential difference between these contacts, after integrating relationship (3.6): But in order to the load, in this case to the voltmeter, to apply this potential difference, it is necessary sliding contacts to lock by the cross connection, on which there is no potential difference indicated. But since metallic plate moves together with the conductor, a potential difference is absent on it. It serves as that cross connection, which gives the possibility to convert this composite outline into the source emf with respect to the voltmeter. Now it is possible wire to roll up into the ring (Fig. **??**) of one or several turns, and to feed it from the current source [9][10][11]. Moreover contacts 1 should be derived on the collector rings, which are located on the rotational axis and to them joined the friction fixed brushes. Thus, it is possible to obtain the revolving magnet. In this magnet should be placed the conducting disk with the opening, which revolves together with the turns of the wire, which serves as magnet, and with the aid of the fixed contacts, that slide on the generatrix of disk, tax voltage on the voltmeter. As the limiting case it is possible to take continuous metallic disk and to connect sliding contacts to the generatrix of disk and its axis. Instead of the revolving turn with the current it is possible to take the disk, magnetized in the axial direction, which is equivalent to turn with the current, in this case the same effect will be obtained.

Different combinations of the revolving and fixed magnets and disks are possible. , and a potential difference between the points 1 r and 2 r in the coordinate system, which moves together with the plate, will be equal .

Since in the fixed with respect to the magnet of the circuit of voltmeter the induced potential difference is absent, the potential difference indicated will be equal by the electromotive force of the generator examined. As earlier moving conducting plate can be rolled up into the disk with the opening, and the wire, along which flows the current into the ring with the current, which is the equivalent of the magnet, magnetized in the end direction.

Thus, the concept of scalar-vector potential gives answers to all presented questions.

9 IV. Conclusion

The unipolar induction was discovered still Faraday almost 200 years ago, but in the classical electrodynamics of final answer to that as and why work some constructions of unipolar generators, there is no up to now. Let us show that the concrete answers to all these questions can be obtained within the framework the concept of scalar-vector potential. This concept, obtained from the symmetrical laws of induction, assumes the dependence of the scalar potential of charge and pour on it from the charge rate. The symmetrization of the equations of induction is achieved by the way of their record with the use by substantial derivative. Different the schematics of unipolar generators are given and is examined their operating principle within the framework of the concept of scalarvector potential.

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Figure 1: 8 Fe

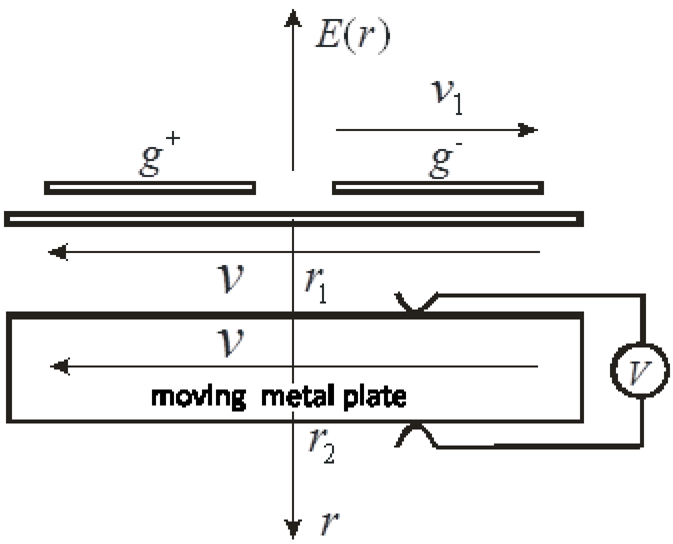

Figure 2:

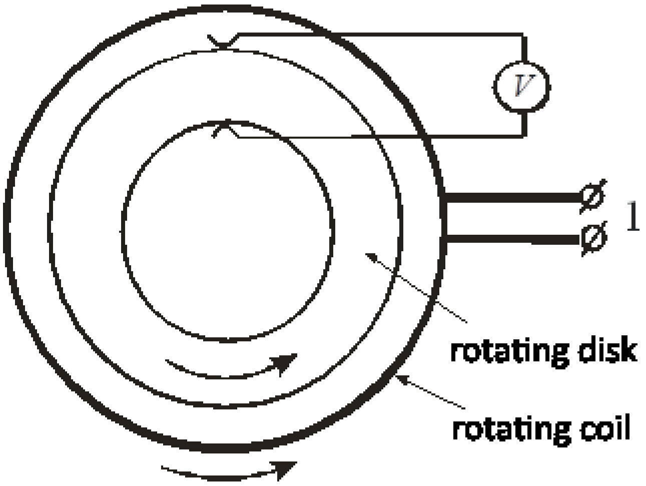

Figure 3:

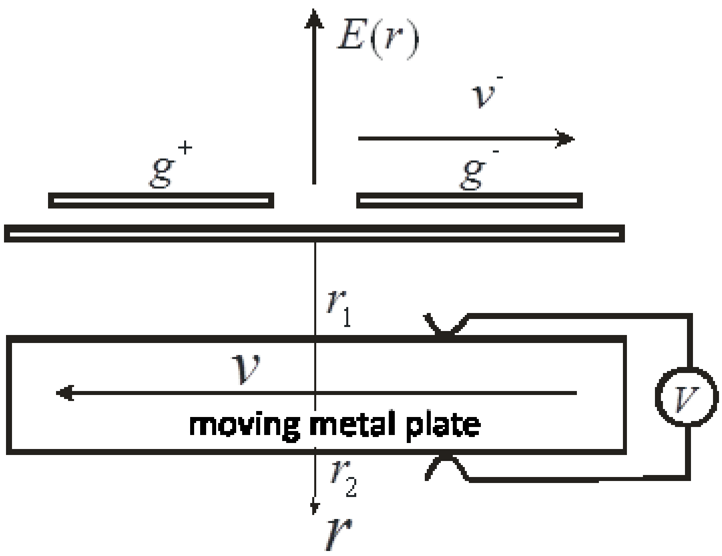

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Figure 4: Fig. 1 :

The relationship (2.21) attest to the fact that in
the case of relative motion of frame of references, between the fields E ? ? and H there is a cross coupling, ?
escape the additional consequences, which were for the
first time examined in the work.
The electricfield E = 2 r outsidethe
??
g
chargedlong rodwith alinear density g decreases as 1 r

[Note: .21) In relationships (2.19-2.21), which assume the , where r isdistance from the centralaxis of the rodto the observation point.]

Figure 5:

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