International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

March 2023 | Issue 54 | Volume 15 | Number 1 | Pages 184-189

CALCULATION OF MAIN PARAMETERS OF INDUCTION LEVITATION DEVICE USED IN VERTICAL AXIS WIND GENERATORS

I.M. Marufov N.S. Mammadov K.M. Mukhtarova N.A. Ganiyeva G.A. Aliyeva

Faculty of Engineering, Azerbaijan State Oil and Industry University, Baku, Azerbaijan
ilkinmarifov@mail.ru, nijatms@gmail.com, kubra.qafarli@b.kru, nigar.atakisiyeva75@mail.ru, gyulnara.alieva-74@mail.ru

Abstract- Starting from the 1960s, a number of scientific works were devoted to magnetic supports. Measuring devices and equipment built on the basis of those supports had high accuracy, but their fields of application were limited due to their weak electromechanical resistance. Induction supports were used in crucible less melting of metals and in transport. When the levitation element is made in the form of a short-circuit loop, in most cases, its height is comparable to the height of the impact loop. In this case, the height of the magnetic system becomes too large and the stability of the system decreases. In addition, since the magnetic currents are not evenly distributed along the height of the levitation element, the current density from it is unevenly distributed along its height. The distribution law of the current density is not known in advance. On the other hand, the law of distribution of magnetic currents is also affected by the nature of the distribution of the magnetic force of the levitation element. As a result, the solution of the problem becomes complicated. In order to reduce the gravity force P_a, *LE* is assembled from wires made of aluminum or aluminum mixed alloys with low specific gravity. To reduce copper losses, *TD* is assembled from copper wires and connected to a constant-amplitude alternating voltage source *~UL*. The electric energy supplied to the loop is converted into magnetic field energy W_m, creating a lifting electromagnetic force F_e, which acts on *LE*. The electromagnetic force F_e, in turn, raises F_1 to a certain height *h*. This height is called levitation height.

Keywords: Levitator, Electromagnetic Force, Core, Wind Turbine, Levitation Height.

1. INTRODUCTION

Starting from 1968, monographs and scientific articles dedicated to the creation of a vertically controlled induction levitator *IL* began to be published, thus laying the foundation of a new scientific direction. In order to increase the output voltage and radial stability of the vertical-axis magnetic levitation wind generator, a short-circuited loop of the induction levitator and the rotor of the quadrupole electric generator are connected to the wind turbine tube. Being levitated in the magnetic field created by the alternating current loop of the levitator, they rotate together under the influence of the wind. The induction levitator is cylinder-shaped and made of electrotechnical pole. Its upper part is intact. The alternating current loop of the levitator is also made in the form of a cylinder, placed inside and at the bottom of it.

Controlled *IL* allows to set, measure and transfer parameters of vertical movement without requiring additional mechanisms (for example, reducer, etc.).

Features of the main destinations:

- Application in vertical axis wind generator
- To accurately generate and measure force and displacement
- Simplicity of construct on and manufacturing technology
- To increase and decrease the values of force and displacement by making the loop multi-section
- Being used as a static support

Unlike the maglev-type wind generator, the output voltage is large and the electromechanical stability is high, levitation height adjustment is the advantages of *IL*. Due to the lack of friction, it can work from very low wind speeds and have a long service life.

At present, scientific research works on the application of different types of levitators in vertical axis wind generators are ongoing. The following levitation conditions are fulfilled in those levitators [2].

$$P_M = P_a \;;\; F_e = KI^2 = P_a \;;\; F_e = KI_1 \times I_2 = P_a \qquad (1)$$

Here P_M is the repulsive force created by the stationary magnet acting on the levitated magnet; F_e electrodynamic force affecting the levitated short circuit W_2; F_e electromagnetic force acting on the aluminum ring by alternating current loop *W*; P_a- gravitational force of levitated element [7]. The condition of levitation must be satisfied when the external force P_x acts on the levitation element in the vertical direction [1].

$$P_M = P_a + P_x \;;\; F_e = KI^2 = P_a + P_x \;;\; F_e = KI_1 I_2 = P_a + P_x \qquad (2)$$

The wind generator consists of a wind turbine 1, an induction levitator 2, an electric generator 3, a radial pad 5 and a pipe of a levitated turbine 6. The support pad is placed on the base 7 together with the pipe 5 (Figures 1 and 2) [10].

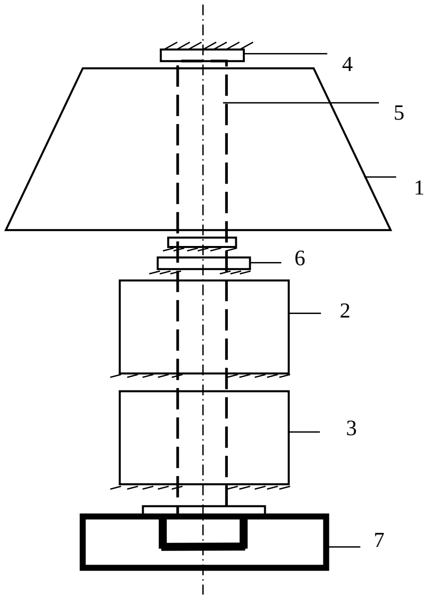

Figure 1. Vertical axis induction levitation wind generator

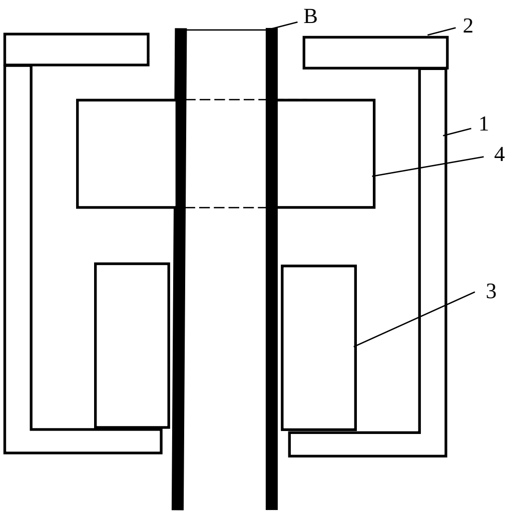

Figure 2. Induction levitator

2. EXPERIMENTAL METHOD AND ITS MAIN PURPOSE

An induction levitator with a triangular steel core was developed for research (Figure 3). The induction levitator consists of an electrotechnical steel core assembled from separate sheets 1, an impact loop 2, a short-circuited aluminum ring (levitation element) 3, a steel anchor and a force transmitter mechanically attached to the levitation element. The container 7 for the load *PY* is placed in the part of the power transmission. Standard weight stones weighing 5, 10, 15, 20, 25 and 30 grams are placed in that bowl. A pointer 8 is attached to the force transmitter 6, and when the force transmitter moves up and down, the levitation height h is determined according to the instructions of the stationary ruler 9.

- Steel core dimensions:
a = 10mm; b = 20mm; c = 50mm; h_c = 80mm
- Dimensions of *TD*:
h_1 = 65 mm; c_1 = 47.553 mm;
- Number of windings and active resistance of *TD*:
W_1 = 1457; r_1 = 40 Ohm
- Dimensions of aluminum rings:
h_2 = 10 mm; h_2 = 15 mm; h_2 = 20 mm; c_2 = 5 mm
- Number of windings of a short-circuited levitation loop:
W_2 = 400; r_2 = 6.19 Ohm; h_2 = 30 mm

First, calculating the weight of aluminum rings based on the following equation: [2]

$$P_a = (g\gamma_a) \times l_2 \times S_2 = \left(26.487 \times 10^3\right) \times \times 108 \times 10^{-3} \times S_2 = 2860.596 \times S_2 \quad (3)$$

where, $g\gamma_a = 9.81 \times 2.7 \times 10^3$

$$l_2 = 2(2a + b + 2c_2 + 4\Delta_0) = 2(2 \times 10 + 20 + 2 \times 5 + 4) \times \times 10^{-3} = 108 \times 10^{-3}\,\text{m} \quad (4)$$

$$S_2 = c_2 \times h_2 = 5 \times 10^{-3} \times h_2$$
$$\Delta_0 = 10^{-3}\,\text{m} \;;\; \Delta_0 = 5 \times 10^{-3}\,\text{m} \quad (5)$$

We count [1-4];

$h_2 = 10 \times 10^{-3}\,\text{m}\,;\; 15 \times 10^{-3}\,\text{m}\,;\; 20 \times 10^{-3}\,\text{m}\,;$

$S_2 = 15 \times 10^{-6}\,\text{m}^2\,;\; 75 \times 10^{-6}\,\text{m}^2\,;\; 100 \times 10^{-6}\,\text{m}^2$

The lifting electromagnetic force is directly proportional to the square of the amperes of the alternating current loop (I_1W_1) and the specific magnetic permeability λ of the air gap in the paths of the stray magnetic currents of the ferromagnetic cylinder [1-4].

$$F_e = 0.5\left(I_1 W_1\right)^2 \lambda \quad (6)$$

Centrifugal electromagnetic forces affect the levitation loop both in the radial direction and ensure the radial stability of the levitation system. Centrifugal radial forces act on the levitation loop in the direction of radius R [8]:

$$F_r = \frac{1}{2} I_2^2 \frac{dL_2}{dR} = \left(I_2 W_2\right)^2 (\mu_0 / 4\pi)\, \Delta(\ln\left(\frac{8R}{r}\right) - 0.75) \quad (7)$$

To reduce the gravity of the levitation loop, it is made of aluminum wires and attached to the tube of the turbine [5]. An industrial frequency voltage U_1 of 50 Hs is supplied to the alternating current loop and the magnetic flux created by the loop is closed by passing through the ferromagnetic cylinder and the ferromagnetic layer of the tube. Since the part of the pipe passing through the levitator is made of ferromagnetic material, the magnetic flux passing through it and the lifting force affecting the levitation loop increase F_e. As a result, the turbine is levitated together with the pipe.

3. SOLUTION OF PROBLEM

Then, according to the equation given above, we get: [9]

1. $h_2 = 10 \times 10^{-3}\,\text{m}\,; c_2 = 5 \times 10^{-3}\,\text{m}$
2. $P_a = 0.143\,\text{N}$
3. $h_2 = 15 \times 10^{-3}\,\text{m}\,; c_2 = 5 \times 10^{-3}\,\text{m}$
4. $P_a = 0.215\,\text{N}$
5. $h_2 = 20 \times 10^{-3}\,\text{m}\,; c_2 = 5 \times 10^{-3}\,\text{m}$
6. $P_a = 0.283\,\text{N}$

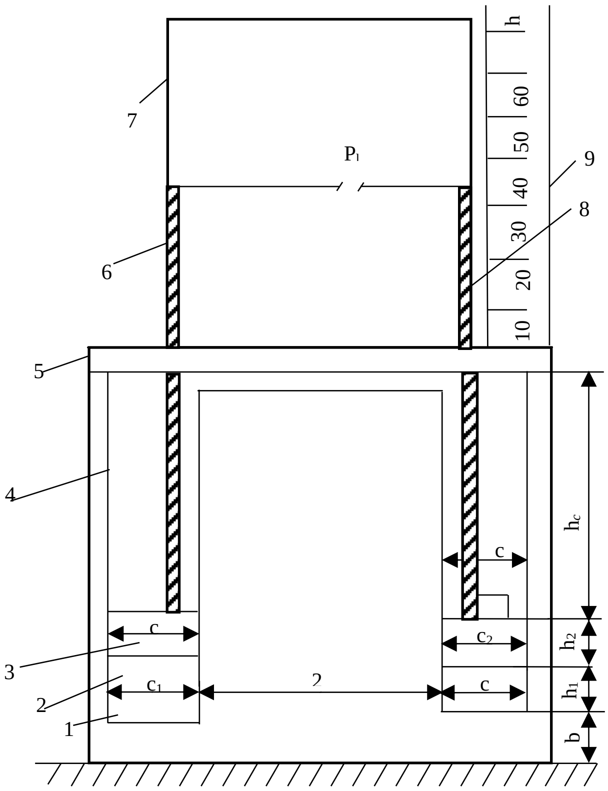

Figure 3. Experiment facility

Cross-sectional area of the middle bar of the steel core [5]

$$S_c = 2ab = 20\times 20\times 10^{-6} = 400\times 10^{-6}\,\text{m}^2 \quad (8)$$

The value of the magnetic induction in the middle rod [6]

$$B_m = \frac{U_1\times\sqrt{2}}{\omega\times S_c\times W_1} = \frac{220\times\sqrt{2}}{314\times 400\times 10^{-6}\times 1457} = 1.7\ \text{Tl} \quad (9)$$

Equivalent height [7]

$$h_{12} = \frac{1}{3}(h_1+h_2) = \frac{1}{3}(65+10)\times 10^{-3} = 25\times 10^{-3}\,\text{m} \quad (10)$$

The electromagnetic force F_e is determined from the levitation equation:

$$F_e = P_a + P_y \quad (11)$$

It is not difficult to determine the electromagnetic force F_e for any values of the levitation height h, since the gravity force P_a of the aluminum ring and the gravity force (load force) P_y caused by the used load my are known [4].

1. When the levitation height h = 0, the load force P_y is maximum, so the electromagnetic force F_e is maximum, i.e. [7-10].

$$F_{\max} = P_a + P_{\max} \quad (12)$$

2. When the levitation height is h = 10 mm

$$F_{10} = P_a + P_{10}$$

3. When the levitation height is h = 20 mm

$$F_{20} = P_a + P_{20}$$

4. When the levitation height is h = 30 mm

$$F_{30} = P_a + P_{30}$$

5. When the levitation height is $h = h_{\max}$= 70 mm

$$F_{70} = P_a + P_{70}$$

In written statements

$$P_{70} < P_{30} < P_{20} < P_{10} < P_{\max}$$

$$F_{70} < F_{30} < F_{20} < F_{10} < F_{\max}$$

and since P_a is assumed to be constant, it is not difficult to determine the dependences of $F_e(h)$, $I_1(h)$, $F_1(h)$ from experience [12].

Let's analyze the mathematical expressions of the dependence of the main parameters h, I_2 and F_e on the load P_y [7-10].

$P_y = 0$, $h = h_{\max}$

$$h = h_{mak} = \frac{U_1}{\omega W_1\sqrt{2\lambda P_a}} - h_{12} = h_{70} \quad (13)$$

$$I_1 = I_{\min} = \frac{K_u U_1}{\omega W_1^2 \lambda\left(h_{12}+h_{\max}\right)} = I_{70} \quad (14)$$

$$F_e = F_{\min} = 0.5\lambda\left(I_{\min}\times W_1\right)^2 = P_a = F_{70} \quad (15)$$

$$P_y = P_{30} \quad (16)$$

$$I_1 = \frac{K_u U_1}{\omega W_1^2 \lambda\left(h_{12}+h_{30}\right)} = I_{30} \quad (17)$$

$$F_e = 0.5\lambda\left(I_{30}\times W_1\right)^2 = P_a + P_{30} = F_{30} \quad (18)$$

$P_y = P_{20}$

$$h = \frac{U_1}{\omega W_1\sqrt{2\lambda\left(P_a+P_{20}\right)}} - h_{12} = h_{20} \quad (19)$$

$$I_1 = \frac{K_u U_1}{\omega W_1^2 \lambda\left(h_{12}+h_{20}\right)} = I_{20} \quad (20)$$

$$F_e = 0.5\lambda\left(I_{20}\times W_1\right)^2 = P_a + P_{20} = F_{20} \quad (21)$$

$P_y = P_{10}$

$$h = \frac{U_1}{\omega W_1\sqrt{2\lambda\left(P_a+P_{10}\right)}} - h_{12} = h_{20} \quad (22)$$

$$I_1 = \frac{K_u U_1}{\omega W_1^2 \lambda\left(h_{12}+h_{10}\right)} = I_{10} \quad (23)$$

$$F_e = 0.5\lambda\left(I_{10}\times W_1\right)^2 = P_a + P_{10} = F_{10} \quad (24)$$

1. $P_y = P_{\max}$ $\quad h = 0$

$$h = \frac{U_1}{\omega W_1\sqrt{2\lambda\left(P_a+P_{\max}\right)}} - h_{12} = 0 \quad (25)$$

$$I_1 = \frac{K_u U_1}{\omega W_1^2 \lambda\left(h_{12}+0\right)} = I_{\max} \quad (26)$$

$$F_e = 0.5\lambda\left(I_{\max}\times W_1\right)^2 = P_a + P_{\max} = F_{\max} \quad (27)$$

From the analysis of the mathematical expressions of the parameters given above, it can be seen that as the load force increases, the levitation height h decreases, while the loop current I and the lifting electromagnetic force F_e increase. Since the results of the analysis coincide with the results of the experiment, the correct determination of the dependences of $F_e(h)$, $I_1(h)$ and $F_1(h)$ from the experiment cannot raise any doubts.

To determine the main characteristics [9] $I_1(h)$, $F_1(h)$, $F_e(h)$ dependencies need to be calculated. These calculations $h_2 = 10\times10^{-3}$ m, $h_{12} = 25\times10^{-3}$ m, $h = 10\times10^{-3}$ m, $h = 20\times10^{-3}$ m, $h = 30\times10^{-3}$ m and $h = 70\times10^{-3}$ m we take for.

1. When the levitation height is h = 0 [10]

$$I_1 = \left(\frac{K_u U_1}{\omega W_1^2 \lambda}\right)\frac{1}{(h_{12}+h)} = \frac{158.421\times10^{-3}}{25\times10^{-3}} = 6.336\,\text{A} \quad (28)$$

$$F_1 = I_1 W_1 = 6.336\times1457 = 9232.827\,\text{A}$$

$$F_e = 0.5\lambda F_1^2 = 10^{-6}\times F_1^2 = 10^{-6}\times(9232.827)^2 = 85.245\,\text{N} \quad (29)$$

where,

$$\left(\frac{K_u U_1}{\omega W_1^2 \lambda}\right) = \frac{0.96\times220}{314\times(1457)^2\times2\times10^{-6}} = 158.421\times10^{-3} \quad (30)$$

$$0.5\lambda = 0.5\times2\times10^{-6} = 10^{-6}\,HN/\text{m}$$

2. Levitation height $h = 10\times10^{-3}$ m [7]

$$I_1 = \frac{158.421\times10^{-3}}{(25+10)\times10^{-3}} = 4.526\,\text{A} \quad (31)$$

$$F_1 = I_1 W_1 = 4.526\times1457 = 6594.876\,\text{A}$$

$$F_e = 10^{-6}\times F_1^2 = 10^{-6}\times(6594.876)^2 = 43.492\,\text{N}$$

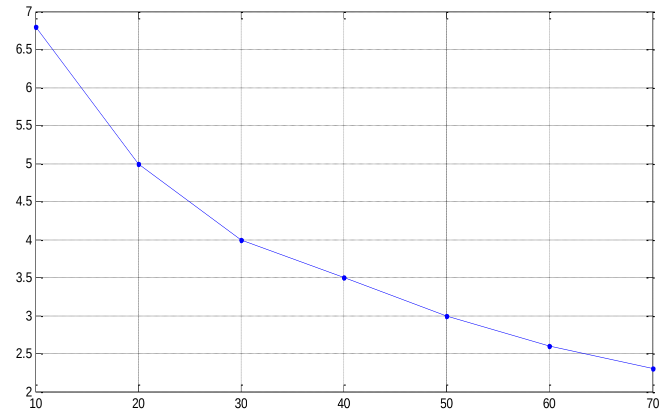

Figure 4. Addiction from experience, case 1

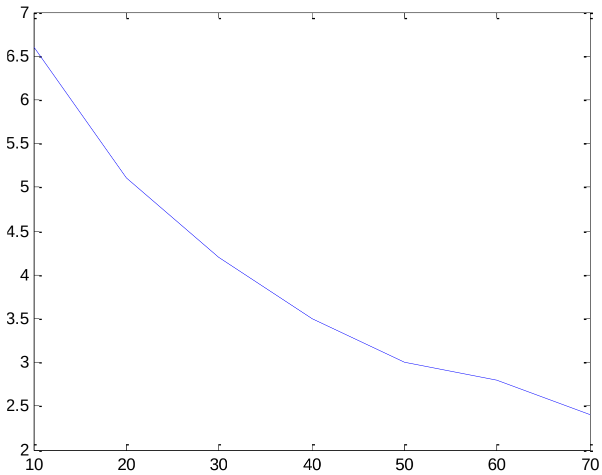

Figure 5. Addiction from experience, case 2

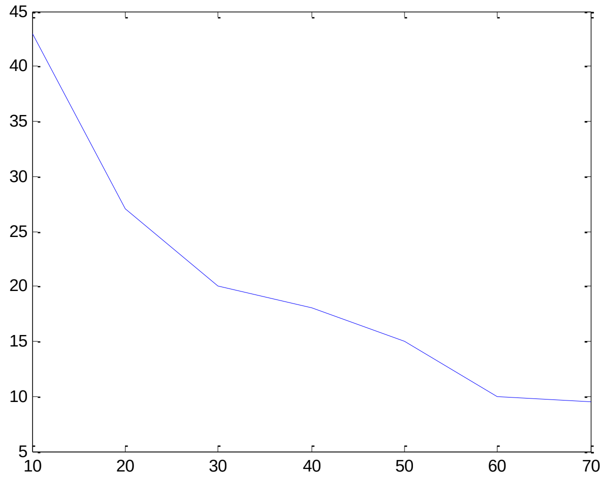

Figure 6. Addiction from experience, case 3

Table 1. $I_1(h)$, $F_1(h)$ and $F_e(h)$ values of dependencies

h_x, 10^{-3}	0	10	20	30	70
I_1, A	6.336	4.526	3.52	2.88	1.67
$F_1\times10^{-3}$ A	9.232	6.594	5.129	4.196	2.37
F_e, N	85.245	43.492	26.31	17.612	5.62

4. RESULT

Magnetic levitators can be created not only on the basis of permanent magnets, but also on the basis of electrodynamic and induction levitators. The newly designed induction levitator allows you to adjust the levitation height and is easily connected to the axis of the generator. The new design of the stator-rotor assembly of the generator allows to significantly increase the output voltage. The turbine tube of the vertical axis wind generator of cylindrical construction is mechanically connected to the short-circuited levitation loop and the four-pole rotor, so they rotate together under the influence of the wind. The constructive features of the rotor have led to raising the output voltage to the required level. Centrifugal forces act on the levitation loop in the radial direction and ensure the radial stability of the levitation system. In order to experimentally study the vertical axis wind generator based on the induction levitator, a research vessel was developed and the main characteristics were calculated and obtained from the experiment. The results obtained from the experiment coincide with the results in the theoretical parts of the vertical axis wind generator.

NOMENCLATURES

λ: Specific magnetic permeability
I: Current of winding
P_x: External force
P_a: Force of gravity of the levitated element
W_2: Electrodynamic force F_e acting on the levitated short circuit
P_M:: Repulsive force produced by a stationary magnet acting on a levitated magnet
W: Number of wraps
K: Displacement coefficient

REFERENCES

[1] G.S. Kerimzade, "Contactless Electric Devices Watching System", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 2, Vol. 2, No. 1, pp. 42-44, March 2010.

[2] G.S. Kerimzade, G.V. Mamedova, "Working Modes for Designing Electrical Apparatuses with Induction-MI with Levitation Elements", Bulletin Buildings, Baku, Vol. 17, No. 1, pp. 42-46, 2015.

[3] Y.R. Abdullaev, G.S. Kerimzade, G.V. Mamedova, "Electric Automation Control Devices", Textbook, Baku, ASOIU, Vol. 5, No. 3, p. 260, 2012.

[4] Y.R. Abdullaev, G.S. Kerimzade, G.V. Mamedova "Electric Devices of Distribution Devices", Tutorial, ASOIU, Vol. 7, No. 1 p. 203, 2013.

[5] G.S. Kerimzade, "Determination of the Optimal Geometric Dimensions of the Peremonial Current Stabilizer, Taking into Account the Temperature of the Overflow of Windings", Electrical Engineering, Vol. 5, No. 9, pp. 40-43, 2013.

[6] Y.R. Abdullaev, G.S. Kerimzade, G.V. Mamedova, "Electric and Electronic Devices", Textbook, ASOIU, Vol. 3, No. 5, p. 351, Baku, Azerbaijan, 2015.

[7] Y.R. Abdullaev, G.S. Kerimzade, "Design of Electric Devices with LE", Electrical Engineering, Vol. 8, No. 5, pp. 16-22, 2015.

[8] Y.R. Abdullaev, G.S. Kerimzade, G.V. Mamedova, "Converter Predesign Efforts", The 5th International Conference on Technical and Physical Problems of Power Engineering (TPE-2009), pp. 61-64, Bilbao, Spain, 3-5 September 2009.

[9] Y.R. Abdullaev, G.S. Kerimzade, G.V. Mamedova, "Calculation of the Power Converter Moving with Levitation Screen", ECAI International Conference, 3rd Edition Electronics, No. 2, pp. 75-78, Pitesti, Romania, 3-5 July 2009.

[10] G.S. Kerimzade, "Optimization of Parameters and the Geometrical Sizes the Precision Stabilizer of the Alternating Current", The 3rd International Conference on Technical and Physical Problems in Power Engineering (ICTPE-2006), pp. 701-703, Ankara, Turkey, 29-31 May 2006.

[11] N.M. Tabatabaei, A. Demiroren, N. Taheri, A. Hashemi, N.S. Boushehri, "SVD-UPFC Based Designation of Versatile Controllers to Damp Low Frequency Oscillations", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 9, Vol. 3, No. 4, pp. 59-67, December 2011.

BIOGRAPHIES

Name: **Ilkin**
Middle Name: **Malik**
Surname: **Marufov**
Birthday: 11.02.1995
Birth Place: Astara, Azerbaijan
Bachelor: Electric Power, Faculty of Energetic, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, 2016
Master: Electric Power, Faculty of Energetic, Azerbaijan State Oil and Industry University Baku, Azerbaijan, 2018
The Last Scientific Position: Associate Teacher, Department of Electromechanics, Azerbaijan State University of Oil and Industry, Baku, Azerbaijan, since 2016
Research Interests: Electrical and Electronic Devices, Automation Control Devices
Scientific Publications: 25 Papers, 5 Scientific-Methodical Sentences

Name: **Nijat**
Middle Name: **Sabahaddin**
Surname: **Mammadov**
Birthday: 23.02.1998
Birth Place: St. Peterburg, Russia
Bachelor: Electrical Engineering, Department of Electromechanics, Energy Faculty, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, 2019
Master: Electrical Engineering, Department of Electromechanics, Energy Faculty, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, 2021
The Last Scientific Position: Chief Laborant, Department of Electromechanics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, Since 2021
Research Interests: Electric Machines, Renewable Energy Sources, PLC
Scientific Publications: 6 Papers, 3 Conference Papers

Name: **Kubra**
Middle Name: **Mammad**
Surname: **Mukhtarova**
Birthday: 25.04.1991
Birth Place: Tartar, Azerbaijan
Bachelor: Techniques and Physics of High Voltages, Faculty of Energetic, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, 2012
Master: Techniques and Physics of High Voltages, Faculty of Energetic, Azerbaijan State Oil and Industry University Baku, Azerbaijan, 2018
The Last Scientific Position: Chief Laborant, Department of Electromechanics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, since 2014
Research Interests: Electrical and Electronic Devices
Scientific Publications: 3 Papers

Name: **Nigar**
Middle Name: **Akif**
Surname: **Ganiyeva**
Birthday: 19.11.1975
Birth Place: Baku, Azerbaijan
Bachelor: Electrical Engineering, Department of High Voltage Technology, Energy Faculty, Azerbaijan State Oil Academy, Baku, Azerbaijan, 1999
Master: Consolidated Information, Department of Informatics, Odessa Law Academy, Kiev, Ukraine, 2015

The Last Scientific Position: Chief Laborant, Department of Electromechanics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, Since 2000
Research Interests: High Voltage Technologies, Electrotechnical Materials
Scientific Publications: 15 Papers, 1 Conference Paper

Name: **Gulnara**
Middle Name: **Alakbar**
Surname: **Aliyeva**
Birthday: 04.08.1974
Birth Place: Baku, Azerbaijan
Bachelor: Department of Power Plants, Faculty of Energy, Azerbaijan State Oil Academy, Baku, Azerbaijan, 1996
The Last Scientific Position: chief laborant, Department of Electromechanics, Azerbaijan State Oil and Industry University, Baku, Azerbaijan, Since 1996
Research Interests: Electric Machines, Renewable Energy Sources
Scientific Publications: 24 Papers, 6 Conference Papers