The Development of Sensitive Measuring Schemes for Capacitive-Semiconductor Humidity Transmitters

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Abstract: Capacitive-semiconductor converters play a crucial role in converting physical quantities with complex parameters due to their positive properties, including measurement accuracy, reliability, manufacturability, and efficient measurement schemes. Experimental results and discussions reveal that at small and medium humidity values (2÷6%), the bridge measuring circuit may not provide the necessary gradation and sensitivity of the output signal. To address this, a measuring circuit is developed to increase sensitivity and linearize the output characteristics of the capacitive-semiconductor converter at low and medium humidity values. The proposed measuring circuit utilizes a bipolar voltage for input value modulation, introducing a new construction principle for capacitive-semiconductor humidity converters. The measuring scheme enhances the accuracy and linearity of static characteristics by utilizing bipolar pulses of varying durations. The study establishes the practical value of pulsed power supply, providing additional opportunities for linearization of conversion characteristics. The presented results contribute to the development of effective measuring circuits for capacitive-semiconductor converters, enhancing their metrological characteristics and widening their applications in monitoring and control systems.

1 INTRODUCTION

In information-measuring equipment capacitance - semiconductor converters of humidity, flow, concentration and temperature of various objects and media are widely used to convert physical quantities with complex parameters, which is explained by a number of their positive properties, such as the accuracy of measurement of the parameters of objects, reliability, manufacturability and efficiency of measurement schemes [1].

The basis of the principle of action of capacitive-semiconductor converter of dispersed media humidity is the dependence between the humidity of the measured medium W and its electro-physical properties, i.e. the change in the active and reactive resistance of the transducers depending on the dielectric constant of the wet medium. The essence of the method is to determine the permittivity of the medium by measuring the active and reactive resistance and energy losses of the electric capacitor, in which the role of the dielectric is played by the media [2].

The capacitive humidity converter was created taking into account the fact that at the same time the temperature, the total content of soluble salts and the humidity of the dispersed medium will be determined at the same point. Consider capacitive semiconductor transducer is a transducer in the form of a probe, allowing measurement in dispersive media without extracting the samples [3].

The design of the capacitance-semiconductor converter is performed so that their longitudinal length is almost an order of magnitude greater than the transverse dimensions and therefore the flow distribution calculations should only take into account changes in the field in the longitudinal direction. The static and dynamic characteristics of the probe capacitance-semiconductor converter can be analyzed in detail on the basis of a sensible mathematical apparatus describing the law of change in the flow distribution along the path of the flow lines, flow distribution changes $I_i(x)$, voltages $U_i(x)$ and the laws of change in the inverse reduction functions [4].

Graph models of the distributed circuit of the capacitive-semiconductor converter are reduced to the transition from complex differential and integral equations to the discretization of algebraic relations, describing and displaying unknown values of the quantities that are the nodal element in the distributed circuit of the converter. When studying and displaying the transformation circuit of the probe capacitance-semiconductor converter based on the graph model, this circuit is conditionally divided into elementary sections Δx, consisting of input and output quantities and parameters, which, in turn, are exposed to external influences of quantities of different physical nature. In this case, the laws of change and distribution of external influencing quantities may be different, because the change in the laws of distribution depends on the physical nature of the chain, where the corresponding parameters are produced [5-8].

2 METHODS AND MATERIALS

Statistical characteristics of a capacitance-semiconductor Converter with distributed parameters can be determined directly from the structural schemes and on the basis of a graph model using descriptions of inter-chain and intra-chain effects, as well as rules for finding the output values of serial, parallel and mixed connections of several transducers. In cases where the use of physical effects or intra-chain conversion for the implementation of the respective devices is required to provide the distribution in space of the parameter [9].

In capacitance-semiconductor converters, the input value is associated with the modulation of the electric flow F_{el}, which is a new principle of construction of capacitive-semiconductor humidity converters and is used to modulate humidity in the ranges $w_{\min} \leq w \leq w_{\max}$. To implement the described principle, a bipolar voltage is used as a reference source. It should be noted that when the input parameters are modulated with a change in the circuit function $\eta_i\left(w_{inp.}\right)$, the transformation parameter changes λ_i. However, you can find a range where the conversion parameter change λ_i is negligible, a schematic function (1) that can be represented as [4]:

$$\eta_{\text{э}}\left(w_{inp.}\right) = \eta_{\text{э}0}\left\lfloor e^{w\left(w_{inp.}\right)+\varphi_0} + 1\right\rfloor. \qquad (1)$$

The static characteristic of the capacitance-semiconductor Converter (2) based on the developed generalized graph model for converting the humidity of dispersed media has the form [10]:

$$U_2 = U_1\eta_1\lambda_1 K_1\left(I_1, I_p\right)K_2\left\lfloor w_{inp.}\,\eta_p\left(w_{inp.}\right)\lambda_p\left(w_{inp.}\right)\right\rfloor K_3\left(U_p, U_2\right)w_{inp.}, \qquad (2)$$

where, U_1 – the input voltage; U_2 – output voltage; λ_i - parameter conversion of the input value; K_1, K_2, K_3 – inter-chain coefficients; $\eta_i\left(w_{inp.}\right)$-circuit function.

Depending on the type of capacitance-semiconductor Converter and its geometric parameters, there may be different laws of distribution of specific reactive and active conductivity, which is described by the circuit function and further on the basis of simulation using a graph model, a feature of the distribution of specific reactive conductivity, which depends on the humidity of the dispersed medium, is revealed.

3 RESULTS AND DISCUSSION

It is established that at small and medium values (2÷6%) of the dispersed media humidity, the bridge measuring circuit does not provide the necessary gradation and sensitivity of the output signal. To increase the sensitivity of the output signal and linearization of the output characteristics of the capacitance-semiconductor converter at low and medium humidity values, a measuring circuit is developed (Figure 1a), allowing with high enough accuracy to convert small changes in the active and reactive resistance of the converters into a DC signal. In this case, the semiconductor converter R_t is a current sensor, which is formed after the conversion of the active and reactive resistance of the converters.

It should be noted that humidity is one of the main quality indicators that affects the cost, physical and technological properties of substances and, first of all, such as grain and its processed products, wood and its derivatives, soil, mining products, food products, minerals fertilizers. In practice, it is necessary to measure humidity in the range from micro- and macro concentration (0,001÷0,1 %) to maximum saturation (80÷90 %) [11-15].

Let's consider some existing capacitive converters and their measuring circuits.

In a semiconductor-resistive humidity converter, the current-voltage characteristic of a semiconductor transistor is used. In the meter, a transistor and measuring electrodes 1 and 2 are connected in series to the power source (Figure 1).

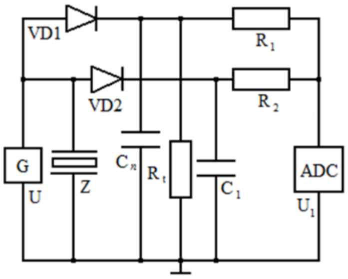

Figure 1: Semiconductor-resistive humidity converter.

The electric current flowing through these electrodes depends on the resistance value of the sample connected between them; the emitter of the transistor is connected to electrode 2 [16-18].

Figure 2 shows a functional diagram of a device for measuring the moisture content of bulk material in a process flow.

The flow of bulk material is divided into two parts, which fill capacitor sensors 2 and 3. Capacitor sensor 2 is connected to an electrical meter [19-20].

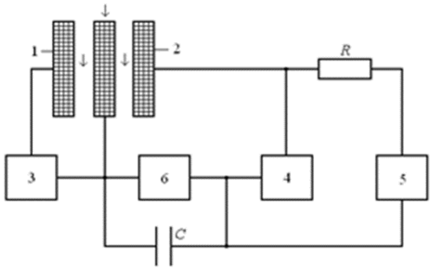

Figure 2: Functional diagram for measuring the moisture content of bulk materials in a process flow.

The flow of bulk material is divided into two parts, which fill capacitor sensors 2 and 3. Capacitor sensor 2 is connected to the electrical capacitance meter 4, capacitor sensor 3 is connected to the electrical capacitance meter 5 through a separating capacitor 6. When a high DC voltage is applied (2-3 K_v) an electric field is excited on the plates of the capacitor 3 sensor in its interelectrode space [21]. The compaction of bulk material in condenser 3 increases with increasing humidity. A capacitance ratio meter 6 is connected to electric capacitance meters 4 and 5. The disadvantage of the above capacitive sensor is that to excite an electric field in the interelectrode space, a high voltage is applied to the plates of the capacitor sensor, and also a change in the density of the bulk material leads to a decrease in the accuracy characteristics of the sensor.

In [22-25], a device for measuring humidity with a sensor consisting of two parts: reference and parametric was proposed. However, due to the peculiarity of the design of its sensor, such a device does not allow determining the soil parameters characteristic of it in a single localized volume, since the sensor, consisting of two parts, in accordance with its design, when measuring, is alternately connected to two adjacent volumes in the places where it is located. In addition, this device, which determines soil salinity using its frequency corrections, allows for a significant measurement error.

To determine the distribution of humidity in dispersed media, an electrical sensor consisting of a set of cylindrical electrodes is used. The disadvantage of this sensor is that the sensor is directly connected to the oscillatory circuit of the generator, i.e. The sensor is an integral element of the oscillatory circuit of the generator and changes in the capacitance of the sensor will lead to disruption of the entire oscillatory circuit, which results in measurement errors [26-27].

Figure 3 shows a block diagram of a device for measuring the humidity of dispersed media.

The test voltage from the measuring electrodes 3 and the comparative voltage from the reference capacitance are supplied to two identical amplitude detectors 5 and 6, and ensure the sensitivity of the device to the sign of the bridge mismatch. At the output of the amplitude amplifier, a difference signal is obtained, which is counted by the indicator.

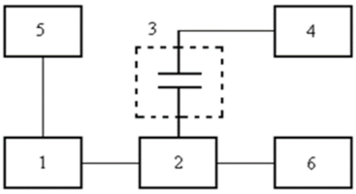

Figure 3: Block diagram of a device for measuring humidity dispersed media.

However, existing designs of converters for monitoring and control systems do not yet meet the requirements, because improvement and creation of new models of capacitive converters require the use of modern scientific achievements in the field of circuit solutions, the effective use of measuring circuits, and appropriate analysis methods.

Using the modified $Z-$transform of Laplace [28], the expressions of the instantaneous value of the output current I_n are obtained, according to which the graph is plotted (Figure 1).

The constant component of this current is $R_1 = R_2 = R$, when expressed by the (3):

$$I_1 = \frac{URR_t(R+2R_n)f}{(R+R_n)^2}\left[\left(e^{\frac{(R+R_n)\upsilon}{2R(R+2R_n)fC_n}}-1\right)e^{\frac{-(R+R_n)}{2R(R+2R_n)fC_n}}C_n-\left(e^{\frac{(R+R_n)\upsilon}{2R(R+R_n)fC_1}}-1\right)e^{\frac{-(R+R_n)}{2R(R+R_n)fC}}\right] \quad (3)$$

and the static characteristic of the capacitive-semiconductor humidity Converter of dispersed media is as follows (4):

$$U_1 = I_1 R_n, \quad (4)$$

where $f = 1/T_0 -$ is the frequency of the power supply.

In continuous feeding ($\upsilon = 1$) (3) is defined by the (5):

$$I_1 = \frac{URR_t(R+2R_n)f}{(R+R_n)^2}\left[\left(1-e^{\frac{-(R+R_n)}{2R(R+2R_n)fC_n}}\right)C_n-\left(1-e^{\frac{-(R+R_n)}{2R(R+2R_n)fC_1}}\right)C_1\right]. \quad (5)$$

and, therefore, the static characteristic of the capacitive-semiconductor humidity Converter is determined by the (6):

$$U_1 = \frac{URR_nR_t(R+2R_n)f}{(R+R_n)^2}\left[\left(1-e^{\frac{-(R+R_n)}{2R(R+2R_n)fC_n}}\right)C_n-\left(1-e^{\frac{-(R+R_n)}{2R(R+2R_n)fC_1}}\right)C_1\right]. \quad (6)$$

Expressions (3) and (4) show that, in General, the characteristic of the circuit transformation is nonlinear both in continuous and in pulsed power. For Figure 1, presents a family of static characteristics of the circuit transformation

$$U_1 = I_1 R_n = F(\Delta C)$$

and

$$U_1 = I_1 R_t = F(\Delta R),$$

constructed by the formula (4) for different values of the signal duration for the case of a differential converter, when

$$C_n = C_0 + \Delta C, \; C_1 = C_0 - \Delta C$$

and

$$R_t = R_0 + \Delta R, \; R_1 = R_0 - \Delta R.$$

A characteristic feature of the graphs is that at small values υ with growth ΔC and ΔR they deviate from the line in the direction of decreasing sensitivity, and for large $\upsilon -$ in the direction of increasing sensitivity. As a result, for each family of static characteristics of the capacitive-semiconductor converter, there is a certain value of the pulse duration υ, at which the characteristic of the circuit conversion is almost linear [29-35].

The Table 1 shows the main characteristics of the conversion circuit at the values of its parameters: $R = 47.10^3 Om$, $\Delta C = 5.10^{-12}\ F$, $f = 25.10^4\ Hz$, $U = 30\ V$, $R_n = 10^6\ Om$.

The nonlinearity of the characteristics of the conversion of the input value of the capacitive-semiconductor humidity Converter of dispersed media is calculated as (7):

$$\beta = \frac{\Delta C_0}{S\Delta C_n} = \frac{U_{on} - S\Delta C_n}{S\Delta C_n}, \quad (7)$$

where ΔC_n and U_{0n} -limit values ΔC and U_{0n} for the range of moisture measurement of dispersed media; $S -$ sensitivity corresponding to the approximating line.

The sensitivity of the capacitive-semiconductor moisture Converter of dispersed media is calculated by the method of least squares according to the (8):

$$S = \frac{\sum_i U_{0i}\,\Delta C_i}{\sum \Delta C_i}. \quad (8)$$

Table 1: Key performance indicators of the transformation.

υ	U_{0n}	S, V/pF	ΔU_n, mV	β, %
0,25	1,00	0,21	-29,4	2,88
0,35	1,84	0,35	-29,8	2,71
0,4	2,16	0,32	-30,4	2,75
0,45	2,19	0,38	-32,6	2,82
0,5	2,25	0,46	-34,4	1,72
0,55	2,48	0,55	-32,6	1,61
0,6	3,15	0,64	-30,5	1,25
0,75	3,59	0,72	-5,41	0,15
0,8	3,83	0,76	6,7	0,17
0,85	4,04	0,81	19,0	0,48
0,9	4,22	0,84	31,1	0,74
0,95	4,33	0,86	40,4	0,94
1,0	4,38	0,88	44,1	1,02

Thus, tabular data indicate that for small pulse durations $\upsilon \leq 0{,}75$, the absolute error of nonlinearity ΔU_n is negative and if $\upsilon \geq 0{,}75$-positive. At this boundary value υ, the nonlinearity β has a minimum value of only 0,15%. Comparison of data for continuous ($\upsilon = 1$) and pulsed power ($\upsilon = 0{,}75$) showed that the transition from continuous to pulsed power nonlinear characteristics of the conversion is reduced by more than six times. This fact gives practical value to the impulse power supply of the circuit, providing additional opportunities for linearization of its transformation characteristics.

4 CONCLUSIONS

Based on the above studies on the development of effective measuring circuits for capacitive-semiconductor measuring converters for measuring the humidity of dispersed media, the following conclusions were made:

1) Analysis of existing literature sources on the development of measuring circuits for capacitive-semiconductor measuring converters indicates that until now there are no effective measuring circuits for capacitive-semiconductor measuring converters that have high metrological characteristics. They mainly use alternating current with sinusoidal and quadrangular voltage as the source of the measuring circuit.
2) Mathematical modeling of the conversion of initial humidity based on inter-circuit graph transitions shows that depending on the type of capacitive-semiconductor measuring converter and the geometric parameters of the measured medium, there may be different distribution laws for the specific reactive and active conductivity of the converter and is described by the circuit function in the form of inter-circuit coefficients. They reveal the features of the distribution of specific reactive conductivity, which depends on the humidity of the dispersed medium.
3) Based on the above experimental studies, it has been established that at low and medium values (2÷6%) of the humidity of dispersed media, the bridge measuring circuit does not provide the required sensitivity value of the output signal of the capacitive-semiconductor measuring transducer. In this case, the output voltage, depending on the humidity of the measured environment, is reduced to 2÷4 mV with a simultaneous decrease in the sensitivity of the converter, therefore, additional measurement errors arise.
4) Pulse power supply of the measuring circuit of the capacitive-semiconductor measuring transducer with a semiconductor current sensor Rt ensures the linearity of the static characteristic. At the same time, measurement errors are significantly reduced as a result of linearization of the static characteristics of the converter. It has been established that the humidity conversion error is significantly related to the periodic charge and discharge of the capacitive-semiconductor measuring converter Cn, since when the charge and discharge of the converter are the same in time, the characteristic becomes linear, therefore, the measurement error decreases many times.
5) Thus, the results obtained indicate that at short pulse $\upsilon \leq 0.75$ durations the absolute nonlinearity ΔUn error is negative, $\upsilon \geq 0.75$ and at - positive. At this boundary value, υ the nonlinearity of the static characteristic β has a minimum value, only 0.15. A comparison of data for continuous ($\upsilon=1$) and pulsed power ($\upsilon=0.75$) showed that when switching from continuous to pulsed power, the nonlinearity of the conversion characteristic decreases by more than six times. This circumstance gives practical value to pulsed power supply of the circuit, which provides additional opportunities for linearization of its conversion characteristics.

REFERENCES

[1] A.V. Delgado, F. González-Caballero, R.J. Hunter, L.K. Koopal, and J. Lyklema. "Measurement and interpretation of electrokinetic phenomena." Journal of Colloid and Interface Science, vol. 309, 2007, pp. 194-224, [Online]. Available: https://doi.org/10.1016/j.jcis.2006.12.075.

[2] F. Zikrillayev, E.B. Saitov, J.B. Toshov, B.K. Ilyasov, and M.B. Zubaydullayev. "A Software Package for Determining the Optimal Composition and Parameters of a Combined Autonomous Power Supply System Based on Renewable Energy Sources." In AIP Conference Proceedings, 2022, vol. 2432, p. 020021.

[3] E.B. Saitov, "Optimal model for additional operation of the storage system for photovoltaic wind power plants." E3S Web of Conferences, Sustainable Energy Systems: Innovative Perspectives, SES 2020, vol. 220, 29 October 2020, [Online]. Available: https://doi.org/10.1051/e3sconf/202022001080.

[4] E.B. Saitov, Y.B. Sobirov, I.A. Yuldoshev, I.R. Jurayev, and S. Kodirov, "Study of Solar Radiation and Wind Characteristics in Various Regions of Uzbekistan." E3S Web of Conferences, Sustainable Energy Systems: Innovative Perspectives, SES 2020, vol. 220, 29 October 2020, [Online]. Available: https://doi.org/10.1051/e3sconf/202022001061.

[5] E.B. Saitov, "Renewable Energy Development in Uzbekistan: Current Status, Problems and Solutions." RSES 2020, E3S Web of Conferences 216, p. 01134, 2020, [Online]. Available: https://doi.org/10.1051/e3sconf/202021601134.

[6] I. Sapaev, E. Saitov, N. Zoxidov, and B. Kamanov, "Matlab-model of a solar photovoltaic station integrated with a local electrical network." IOP Conference Series: Materials Science and Engineering, 883, 1, 012116, IOP Publishing, 2020/7/1, [Online]. Available: https://doi.org/10.1088/1757-899X/883/1/012116.

[7] E.B. Saitov, Sh. Kodirov, B.M. Kamanov, N. Imomkulov, and I. Kudenov, "Increasing the

efficiency of autonomous solar photovoltaic installations for power supply of agricultural consumers." AIP Conference Proceedings 2432, p. 040036, 2022, [Online]. Available: https://doi.org/10.1063/5.0090439.

[8] F. Zikrillayev, E.B. Saitov, J.B. Toshov, B.K. Ilyasov, and M.B. Zubaydullayev, "A software package for determining the optimal composition and parameters of a combined autonomous power supply system based on renewable energy sources." AIP Conference Proceedings 2432, p. 020021, 2022.

[9] A.T. Rakhmanov and S.F. Kuznetsov, "Reliability of Semiconductor Converters of Temperature and Humidity of Disperse Media with Respect to Catastrophic Failures." International Journal of Advanced Research in Science, Engineering and Technology, vol. 8(12), December 2021, ISSN: 2350-0328.

[10] A.T. Rakhmanov, S.F. Kuznetsov, A.K. Khamrayev, and S.S. Gulyamov, "Matching of line-approximated static characteristics of temperature and moisture converters and automatic bridge." Science and World. International scientific journal, no. 4 (68), 2019, vol. 1, pp. 63-67.

[11] A.T. Rakhmanov, S.F. Kuznetsov, and A.K. Khamrayev, "Error of static characteristics of disperse media moisture when modeling the exponential process." Science and World. International Scientific Journal, vol. 1, no. 68, 2019, pp. 67-71.

[12] A.T. Rakhmanov and S.F. Kuznetsov, "Determination of Dynamic Errors of Converter Temperature and Humidity Measured Quickly Changing Output Signals." International Journal of Advanced in Science, Engineering and Technology, vol. 6, no. 4, 2019, pp. 8945-8949.

[13] E.B. Saitov and U.M. Akhmedov, "Tracking maximum power point of photovoltaic modules." AIP Conference Proceedings, vol. 2789, 2023, p. 060005.

[14] N. Zikrillayev, K. Ayupov, Z. Mamarajabova, E. Saitov, and I. Sabitova, "Adaptation and optimization of a photovoltaic system for a country house." E3S Web of Conferences, vol. 383, 2023, p. 04054.

[15] E. Saitov, I. Kudenov, F. Qodirova, D. Askarov, and M. Sultonova, "Analysis of the performance and economic parameters of different types of solar panels taking into account degradation processes." E3S Web of Conferences, vol. 383, 2023, p. 04059.

[16] E. Saitov, G. Khushakov, U. Masharipova, O. Mamasaliyev, and S. Rasulova, "Investigation of the working condition of large power solar panel cleaning device." E3S Web of Conferences, vol. 383, 2023, p. 04060.

[17] N. Zikrillayev, E. Saitov, J. Toshov, B. Muradov, and D. Muxtorov, "Autonomous Solar Power Plant for Individual use Simulation in LTspice Software Package Booster Voltage Converter." Proceedings of International Conference on Applied Innovation in IT, vol. 11, no. 1, 2023, pp. 207-211.

[18] B. Yuldoshov, E. Saitov, J. Khaliyarov, S. Toshpulatov, and F. Kholmurzayeva, "Effect of Temperature on Electrical Parameters of Photovoltaic Module." Proceedings of International Conference on Applied Innovation in IT, vol. 11, no. 1, 2023, pp. 291-295.

[19] E. Saitov, O. Jurayev, S. Axrorova, J. Ismailov, and B. Baymirzaev, "Conversion and use of Solar Energy Calculation Methodology for Photovoltaic Systems." Proceedings of International Conference on Applied Innovation in IT, vol. 11, no. 1, 2023, pp. 227-232.

[20] E.B. Saitov and T.B. Sodiqov, "Modeling an Autonomous Photovoltaic System in the Matlab Simulink Software Environment." AIP Conference Proceedings, vol. 2432, 2022, p. 020022.

[21] E.B. Saitov, Sh. Kodirov, B.M. Kamanov, N. Imomkulov, and I. Kudenov, "Increasing the Efficiency of Autonomous Solar Photovoltaic Installations for Power Supply of Agricultural Consumers." AIP Conference Proceedings, vol. 2432, 2022, p. 040036.

[22] E.B. Saitov, Y.M. Kurbonov, and B.M. Botirov, "Analysis of the influence of temperature on the operating mode of a photovoltaic solar station." IOP Conference Series: Earth and Environmental Science, vol. 614(1), 2020.

[23] E.B. Saitov, "Optimal model for additional operation of the storage system for photovoltaic wind power plants." E3S Web of Conferences, vol. 220, 2020.

[24] E.B. Saitov, Y.B. Sobirov, I.A. Yuldoshev, I.R. Jurayev, and S. Kodirov, "Study of Solar Radiation and Wind Characteristics in Various Regions of Uzbekistan." E3S Web of Conferences, vol. 220, 2020.

[25] E.B. Saitov, J.B. Toshov, A.O. Pulatov, B.M. Botirov, and Y.M. Kurbanov, "Networked interactive solar panels over the roof photovoltaic system (PVS) and its cost analysis at Tashkent state technical University." E3S Web of Conferences, vol. 216, 2020.

[26] E.B. Saitov, "Renewable energy development in Uzbekistan: Current status, problems and solutions." E3S Web of Conferences, vol. 216, 2020.

[27] E. Saitov and J. Toshov, "Portable autonomous solar power plant for individual use." E3S Web of Conferences, vol. 139, 2019.

[28] E.B. Saitov, M.K. Bakhadyrkhanov, S.A. Valiev, N.F. Zikrillaev, and S.A. Tachilin,"Silicon photovoltaic cells with clusters of nickel atoms." Applied Solar Energy (English translation of Geliotekhnika), vol. 52, no. 4, 2016, pp. 278-281.

[29] H. Schaumberg, "Sensors: Transl. from German/Under the general editorship," Tashkent: Tashkent State Technical University, 2002, 147 p.

[30] T.D. Japaridze, "Patent No. 171809 of the Russian Federation. Method for measuring the moisture content of bulk materials." 2002, no. 9, p. 164.

[31] Yu.M. Romanenko and V.A. Emelyanov, "Patent No. 379864 of the Russian Federation. Device for measuring soil moisture." 2005, no. 20, p. 78.

[32] A.I. Moiseev, "Development of capacitive converters of bulk materials." State and prospects for the development of information technologies: - Penza: Perm State Technical University, 2005, pp. 38-42.

[33] B.M. Kulwicki, "Ceramic sensors and transducers." J. Phys. Chem. Solids, vol. 45, no. 10, 2002, p.1015.

[34] "Universal converter. Universal transducer: Application no. 19929264." Germany, Knoll Meinkard, no. 19929264.

[35] A.I. Kuchimov. "Electronics and circuit design: Textbook." M.: Helios ARV, 2004, 336 p.