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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
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NEWS

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MODELING CAPACITANCE OF CAPACITIVE TRANSDUCER

Abstract. The modern circulating electrical machines used to produce electric power and act as drivers are wide spread in electric-power industry. One of the typical mechanical troubles electrical machines encounter is rotor eccentricity. It is usually accompanied by non-uniformity of air gap between stator and rotor and formation of additional magnetic fields in it which leads to deterioration of electromechanical features of electrical machines and increase in electric power loss. With a large displacement of the rotor, the rotor core starts to rub against the stator core. It is accompanied by fairing of cores and overheating. Severe overheat of rotor core can lead to rotor coil burning-out, and overheat of stator core is accompanied by accelerated thermal deterioration of insulation and a subsequent fault in its coil. This can lead to total damage of the machine. Nowadays, rotor eccentricity can be determined by using methods based on measuring values which are caused by additional magnetic fields. However, the sensitivity of the methods mentioned is limited by the need of considering the interferences due to variation of mains settings and loads. In this sense, capacitive sensors used as measuring capacitive transducers are known to be more perspective diagnostic means for determination of rotor eccentricity. However, there are no methods for calculation of parameters of such measuring transducers with complex geometry of electrodes.

The current document features a simple method for calculation of a capacitive transducer with electrodes of various shapes. This method comprises modeling the transducer electro-static field using nets method and calculation of capacitance based on the empirical formula proposed. As an example, the method efficacy is checked by determination of plate capacitor capacitance using the method proposed and classical formula. It was demonstrated that the modeling accuracy did not exceed 5%.

The example included evaluating a capacitance for electrodes with toothed rotor of electrical machines and with different positions of capacitive transducer plates relative to rotor slot opening. This document also contains the principle of forming boundary conditions and electrostatic potential distribution patterns, and the calculation of capacitance.

Key words: diagnostics method, rotor eccentricity, capacitive transducers.

Introduction. In electric-power industry, for example, when diagnosing moving parts of electrical machines (EM) the capacitive transducers (CT) [1-4] are widely used because they provide simple operation and reliable performance. As it is known, changes in transducers capacitance can happen both due to movement of target machine part and its circulation on a shaft. The example [4] shows measuring rotor eccentricity during operation when one of CT electrodes has constant geometrical sizes and the other one represents a circulating toothed rotor core as shown in the figure 1,a: where 1 and 2 – stator and rotor cores; 3 – armature key; 4 – CT electrode; 5 – EM air gap.

Since CT capacitance during rotor circulation changes both because of rotor eccentricity value and open slots of rotor that follow along its electrodes development of methods for diagnosing EM rotor eccentricity is simply impossible without modeling transducer capacitance value depending on the conditions mentioned.

As it is known [5-9], there are many ways that facilitate calculation of capacitor capacitance with various electrode shapes. However, their analysis has shown that it is too difficult to use some of them even equipped with computer technology. Some of them describe only particular cases for electrode surfaces and others cannot provide the required accuracy.

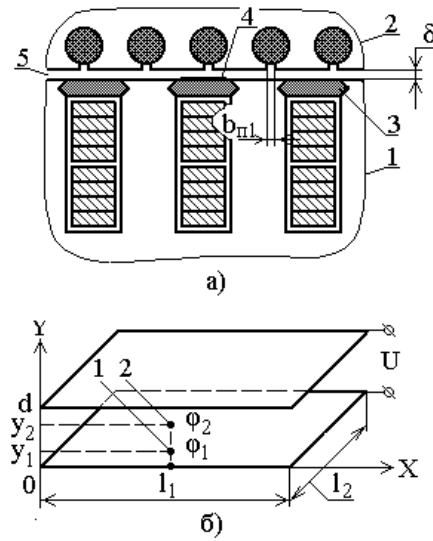


Figure 1 – EM specific design features and calculation diagram

In connection with this, electrical capacitance of two electrodes with various shapes can be calculated the following way.

According to [10-15] electro-statical field density in any point between the two electrodes of the capacitor is a constant value. In light of this and the figure 1:

$$E = \frac{U}{d} = \frac{\varphi_2 - \varphi_1}{y_2 - y_1} = \frac{\Delta\varphi}{\Delta y}, \quad (1)$$

where φ_1 and φ_2 - electro-statical field potentials in points 1 and 2 with respect to lower capacitor plate; y_1 and y_2 - coordinates y of points 1 and 2; U and d - voltage and the gap between capacitor electrodes.

Then, taking into consideration equation correlations (1) in order to determine the capacitance of air plate capacitor we can use the following empirical dependence:

$$C = \varepsilon_0 l_1 l_2 \frac{\varphi_2 - \varphi_1}{y_2 - y_1} = \varepsilon_0 l_1 l_2 \frac{\Delta\varphi}{\Delta y}, \quad (2)$$

where l_1 and l_2 - breadth and length of capacitor electrodes; ε_0 - electrical permittivity of vacuum.

Since the capacitor electro-statical field is potential and there are no free electro-statical field sources in it then taking into consideration the diagram in the figure 1 and [13-17] the field can be described by Laplace equation:

$$\partial^2 \varphi / \partial x^2 + \partial^2 \varphi / \partial y^2 = 0. \quad (3)$$

Analysis of [17-20] makes it clear that it is hard or sometimes impossible to get an analytical expression from direct solution of equation (3) with complex electrode shapes whereas the net method provides a simple answer. Here, partial Poisson equations [21-23] (3) for i, k – th node in the figure 2 are replaced by expressions:

$$\frac{\partial^2 \varphi_x}{\partial y^2} \approx \frac{\varphi_{x(i,k+1)} - 2\varphi_{x(i,k)} + \varphi_{x(i,k-1)}}{h^2}; \quad (4)$$

$$\frac{\partial^2 \varphi_x}{\partial z^2} \approx \frac{\varphi_{x(i+1,k)} - 2\varphi_{x(i,k)} + \varphi_{x(i-1,k)}}{h^2}. \quad (5)$$

As a result in i, k – th node electro-statical field potential can be described as:

$$\varphi_{x(i,k)} = \frac{1}{4} (\varphi_{x(i+1,k)} + \varphi_{x(i-1,k)} + \varphi_{x(i,k+1)} + \varphi_{x(i,k-1)}) \quad (6)$$

The efficacy of the mathematical model for solution of such issues can be easily demonstrated in an example with determination of capacitance of air plate capacitor [24-25]. According to [10] and the figure 1,6 plate capacitor capacitance is:

$$C = \epsilon_0 l_1 l_2 / d \tag{7}$$

When using the net method for modeling electro-statical field between MF electrodes the area in question is divided into squares with the help of $k_m + 2$ horizontal and $i_m + 2$ vertical lines as shown in the figure 2 with square side h . When k - th horizontal line crosses i - th vertical line it forms i, k - th node where k_m and i_m - number of nodes in target area in vertical and horizontal direction where electro-statical field potential is calculated based on equation (6). In the figure 2 these nodes are located in the area outlined with dotted line. Electrode breadth l_1 of capacitor and distance d between its electrodes on calculation diagram can be described according to:

$$l_1 = x_2 - x_1 \text{ and } d = y_2 - y_1, \tag{8}$$

where x_1, x_2 and y_1, y_2 - coordinates of capacitor electrodes in cells.

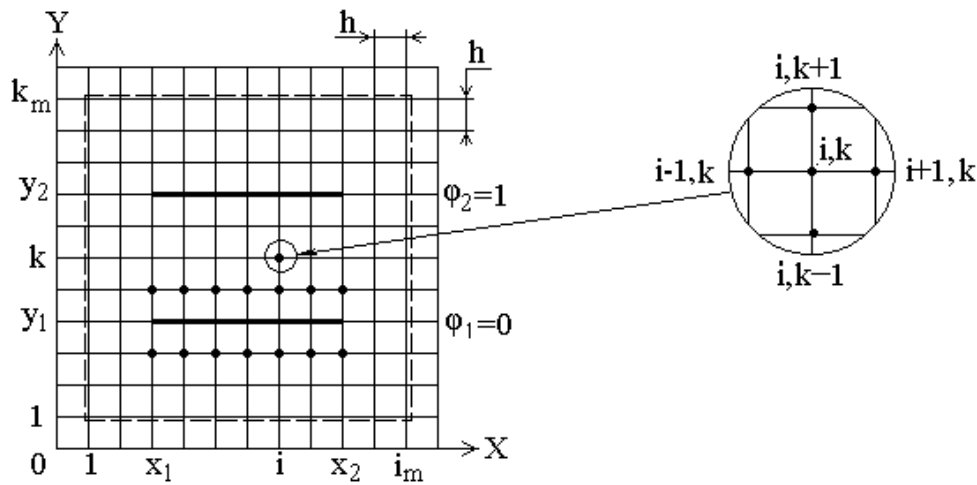


Figure 2 – Calculation diagram

When modeling the electro-statical field the upper electrode potential y_2 is assumed to be equal to one and the lower one ϕ_1 is to zero. After iteration procedure, all nodes with coordinates $k = 0$ and $k = k_m + 1$ are assigned nodes potentials with $k = 1$ and $k = k_m$ and all nodes with coordinates $i = 0$ and $i = i_m + 1$ are assigned nodes potentials with $i = 1$ and $i = i_m$ which is boundary conditions for the given type of task.

Potentials of each node within outlined area are calculated with the help of computer based on iteration method which assumes potential calculation beginning from the left lower corner and then back from the right lower corner of the area. After each iteration procedure boundary conditions are reset again and iteration number is chosen so as to minimize errors.

After calculation of potentials in nodes the capacitor capacitance can be calculated using mathematical expression (2) as

$$C = \epsilon_0 l_1 l_2 \frac{\sum \phi_n / N - \phi_1}{h} = \epsilon_0 l_1 l_2 \frac{\sum \phi_n}{Nh}, \tag{9}$$

ϕ_n - potentials of all nodes adjacent to electrode with $\phi_1 = 0$; N - number of nodes adjacent to CT electrode with $\phi_1 = 0$. In the figure 2 all nodes that adjacent to electrode with potential $\phi_1 = 0$ are marked with dots.

As one can see from the mathematical expression (9) (which defines capacitance through traditional method [10] with constant plate characteristics) the capacitor capacitance depends on the distance between the plates that is determined by air gap which sizes are shown in the table.

EM air gap

Revolutions per minute, rpm	Gap, mm, with engine power, kW					
	Up to 0,2	0,2-1	1-2,5	2,5-5	5-10	10-20
500-1500	0,2	0,25	0,3	0,35	0,4	0,4
3000	0,25	0,3	0,35	0,4	0,5	0,65

If for calculation diagram in the figure 2 we assume $h = 0,01$ m, $k_m = 11$ and $i_m = 11$ cells and coordinates $x_1 = 3$, $x_2 = 9$, $y_1 = 4$, $y_2 = 8$ then potentials modeling results in nodes can be presented as tables shown in the figure 3.

	0.00	0.76	0.77	0.78	0.80	0.80	0.80	0.80	0.78	0.77	0.75	0.74	0.00
k_m	0.76	0.76	0.77	0.78	0.80	0.80	0.80	0.80	0.78	0.77	0.75	0.74	0.74
	0.75	0.75	0.77	0.79	0.80	0.81	0.81	0.80	0.79	0.77	0.74	0.73	0.73
	0.73	0.73	0.76	0.79	0.81	0.82	0.83	0.82	0.80	0.76	0.73	0.71	0.71
	0.67	0.67	0.69	1.00	1.00	1.00	1.00	1.00	1.00	0.70	0.67	0.67	0.67 $\varphi=1$
	0.58	0.58	0.60	0.62	0.66	0.67	0.67	0.67	0.67	0.66	0.63	0.61	0.61
	0.49	0.49	0.48	0.48	0.49	0.50	0.50	0.50	0.51	0.51	0.51	0.51	0.51
	0.39	0.39	0.36	0.34	0.33	0.33	0.33	0.33	0.34	0.38	0.40	0.41	0.41
	0.33	0.33	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.33	0.33	0.33 $\varphi=0$
	0.29	0.29	0.27	0.23	0.19	0.18	0.17	0.18	0.19	0.21	0.24	0.27	0.27
	0.26	0.26	0.25	0.23	0.21	0.19	0.19	0.19	0.20	0.21	0.23	0.25	0.25
1	0.25	0.25	0.24	0.23	0.21	0.20	0.19	0.19	0.20	0.21	0.23	0.24	0.24
	0.00	0.25	0.24	0.23	0.21	0.20	0.19	0.19	0.20	0.21	0.23	0.24	0.00
		1											i_m

Figure 3 – Potentials modeling results in nodes of electro-static fields of two-plate electrode

Then, CT capacitance calculated based on mathematical expression (9) using net method amounted to 1.55pf and 1.442pf accordingly. The net method accuracy was 7.001%. Therefore, such method for determination of air CT capacitance is simple and provides sufficient accuracy within the diagnostics system.

Based on the model proposed it is easy to calculate CT capacitance variation of asynchronous motor (AM) rotor with open slots. If we assume CT breadth l_1 , air gap δ and rotor slot opening breadth b_{n1} equal to 5, 3 and 3 cells then potentials modeling results in nodes with CT electrode located above rotor slot opening can be presented as tables shown in the figure 4. Then, CT capacitance was 2.628pf. At the same time when CT electrode was located above the middle rotor tooth the capacity amounted to 2.736pf, as shown in the figure 5.

		$\varphi=0$			$\varphi=1$				$\varphi=0$			
k_m	0.00	0.00	0.00	0.39	1.00	1.00	1.00	1.00	0.42	0.00	0.00	0.00
	0.00	0.00	0.00	0.39	1.00	1.00	1.00	1.00	0.42	0.00	0.00	0.00
	0.12	0.12	0.19	0.32	0.50	0.61	0.64	0.61	0.53	0.38	0.21	0.12
	0.13	0.13	0.17	0.25	0.35	0.42	0.44	0.42	0.36	0.27	0.19	0.14
	0.09	0.09	0.11	0.16	0.22	0.27	0.29	0.27	0.22	0.17	0.13	0.10
	0.00	0.00	0.00	0.00	0.00	0.16	0.18	0.16	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.08	0.10	0.09	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.05	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00
		1	$\varphi=0$						$\varphi=0$			i_m

Figure 4 – Potentials modeling results in nodes of electro-static fields of plate electrode and air gap area above AM slot opening

	φ=1				φ=0				φ=1				
k_m	0.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.00
	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00
	0.62	0.62	0.58	0.48	0.30	0.16	0.13	0.15	0.25	0.44	0.59	0.65	0.65
	0.41	0.41	0.38	0.32	0.24	0.17	0.14	0.16	0.21	0.30	0.38	0.42	0.42
	0.23	0.23	0.22	0.19	0.16	0.13	0.12	0.12	0.14	0.18	0.22	0.24	0.24
	0.00	0.00	0.00	0.00	0.00	0.09	0.08	0.08	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.04	0.05	0.05	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1		φ=0						φ=0		i_m	

Figure 5 – Potentials modeling results in nodes of electro-static fields of plate electrode and air gap area above middle tooth of AM rotor

Thus, CT capacitance with AM rotor can be determined the following way:

$$C_{ин} = C_{ин,0} + C_{ин,m} \sin(2\pi f_2 t), \quad (10)$$

where $C_{ин,0}$ and $C_{ин,m}$ - constant component and CT capacitance variable amplitude; $f_2 = nZ_2 / 60$ - CT capacitance variable amplitude frequency; n - rotor rpm; t - time.

According to the net method in the figure 4 capacitance values are $C_{ин,0} = 2.682\text{pf}$ and $C_{ин,m} = 0.054\text{pf}$.

The example mentioned shows it obviously that the method proposed allows simple and quite precise modeling CT capacitance, for example, for diagnosing rotor eccentricity regarding electrode shapes.

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МОДЕЛЬДЕУ ЭЛЕКТР СЫЙЫМДЫЛЫҒЫН ӨЛШЕУ ТҮРЛЕНДІРГІШ

Аннотация. Қазіргі заманғы айналмалы электр машиналары электр энергетикасында электр энергиясын өндіру үшін және жетек ретінде кеңінен қолданылады. Олардың өзіне тән механикалық зақымдануының бірі ротордың эксцентриситеті болып табылады. Әдетте ол статор мен ротор арасындағы әуе саңылауының біркелкі еместігімен және онда қосымша магниттік өрістердің пайда болуымен сүйемелденеді. Бұл жағдайлардың бәрі электр машиналарының механикалық сипаттамаларын нашарлауына және электр энергиясының шамадан тыс шығындануна әкеледі. Егерде ротордың жылжуы үлкен болса онда роторды өзегі статор өзегін үйкелей бастайды. Бұл өзектердің қызуына әкеп соғады. Ротордың өзегі қатты қызуы ротор орамының балкуына әкеп соғуына мүмкін, ал статордың өзегінің қызуы статор орамының окшаулағышарының жылулық қартайуын тездетеді кейінен орамдарда қысқа тұйықталулар болады. Бұл ретте электр машинасы толығымен істен шығады.

Қазіргі уақытта ротордың эксцентриситетін анықтау үшін негізінен қосымша магнит өрістерінің пайда болуынан туындаған шамаларды өлшеуге негізделген әдістер қолданылады. Бірақ олардың сезімталдығы қоректендіруші желінің электр параметрлерінің тербелісінен және жүктемесінен туындаған кедергілерден ауытқудың қажеттілігімен шектеледі. Бұл жағдайда ротордың эксцентриситетін диагностикалау жүйелері үшін өлшеуіш түрлендіргіш ретінде сыйымдылық датчиктерді пайдалану неғұрлым болашағы болып табылады. Алайда электродтардың күрделі формасымен осындай өлшеуіш түрлендіргіштің параметрлерін есептеу әдісі жоқ.

Ұсынылған жұмыста электродтардың еркін формасындағы сыйымдылықты өлшеуіш түрлендіргішті есептеудің қарапайым әдісі ұсынылған, бұл түрлендіргіштің электростатикалық өрісін тор әдісімен модельдеуге және келтірілген эмпирикалық формула бойынша сыйымдылықты есептеуге негізделген. Осы әдістің барабарлығын жазық конденсатордың сыйымдылығын анықтау мысалында тексеру жүзеге асырылды, оның шамасы ұсынылып отырған әдісті пайдалана отырып және классикалық формула бойынша анықталған. Модельдеудің қателігі 5%-дан аспады.

Бұл әдісті қолдану мысалы ретінде электр машина роторының тісті беті бар электродтар үшін сыйымдылықты анықтауына қатысты өлшеуіш түрлендіргіш пластинасының түрлі жағдайларында жүзеге асырылды. Сонымен қатар, шекаралық жағдайларды қалыптастыру принципі және электростатикалық өріс потенциалдарының таралу сұлбасы келтірілген, сондай-ақ сыйымдылықтар есептелген.

Түйіндік сөздер: диагностика әдістемесі, ротордың эксцентриситеті, сыйымдылық өлшеуіш түрлендіргіштер.

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МОДЕЛИРОВАНИЕ ЭЛЕКТРИЧЕСКОЙ ЕМКОСТИ ИЗМЕРИТЕЛЬНОГО ПРЕОБРАЗОВАТЕЛЯ

Аннотация. Современные вращающиеся электрические машины широко используются в электроэнергетике для производства электроэнергии и в качестве привода. Одним из их характерных механических повреждений является эксцентриситет ротора. Обычно он сопровождается неравномерностью воздушного зазора между статором и ротором и возникновением в нем дополнительных магнитных полей. Что приводит к ухудшению электромеханических характеристик электрической машины и увеличением потерь электроэнергии. При большом смещении ротора сердечник ротора начинает тереться о сердечник статора. Что сопровождается «заливом» сердечников и их разогревом. Сильный разогрев сердечника ротора может привести к выплавлению обмотки ротора, а разогрев сердечника статора сопровождается ускоренным тепловым старением изоляции и последующим коротким замыканием в ее обмотке. В таких случаях машина может полностью выйти из строя.

В настоящее время для выявления эксцентриситета ротора в основном используются методы, основанные на измерении величин вызванных появлением дополнительных магнитных полей. Однако их чувствительность ограничена необходимостью отстройки от помех, вызванных колебанием электрических параметров питающей сети и нагрузки. В этом отношении более перспективны системы диагностики эксцентриситета ротора, у которых в качестве измерительного преобразователя используются емкостные датчики. Однако метод расчета параметров таких измерительного преобразователя со сложной формой электродов отсутствует.

В предлагаемой работе предложен простой метод расчета емкостного измерительного преобразователя с произвольной формой электродов основанный на моделировании электростатического поля этого преобразователя методом сеток и расчетом емкости по приведенной эмпирической формуле. Осуществлена проверка адекватности этого метода на примере определения емкости плоского конденсатора, величина которого определялась с использованием предлагаемого метода и по классической формуле. Показано, что погрешность моделирования не превысила 5%.

В качестве примера использования этого метода осуществлено определение емкости для электродов с зубчатой поверхностью ротора электрической машины в разных положениях пластины измерительного преобразователя относительно раскрытия паза. Также приведен принцип формирования граничных условий и картины распределения потенциалов электростатического поля, а также рассчитаны емкости.

Ключевые слова: методика диагностики, эксцентриситет ротора, емкостные измерительные преобразователи.

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REFERENCES

- [1] Novozhilov A.H., Yussupova A.O., Novozhilov T.A.. Choosing methods for determination of rotor eccentricity of electrical machines // Vestnik PGU. Serya Energeticheskaya. Pavlodar, 2016. N 4. P. 117-126.
- [2] Levent Beker, Ayden Maralani, LiweiLin, Albert P.Pisano. Modeling, fabrication, and characterization of SiC concentrically matched differential capacitance output pressure sensors // Sensors and Actuators A: Physical. Vol. 273. 15 April 2018. P. 293-302. <https://doi.org/10.1016/j.sna.2018.02.027>
- [3] Yang J., Li W., Han Y., Zhao Y. (2016) Research on the effects of cable on the reactive power of urban distribution network // Dianli Xitong Baohu yu Kongzhi/Power System Protection and Control. 44(16). P. 143-148. DOI:10.7667/PSPC151475.
- [4] Atsyukovskiy V.A. Differential capacitance sensors. M.: Gosenergoizdat, 1960. 102 p.
- [5] Capacitance calculation / Edited by Yu.Ya. Yossel, E.S. Kochanov, M.G. Strunskiy. M.: Energoizdat, 1948. 288 p.
- [6] Dzhezhora A.A. Capacitance transducers and calculation methods. Minsk: Belorusskaya nauka, 2008. 352 p.
- [7] Wang Y., Wei G., Yang H., Chen H., Ouyang Z. (2018) Novel Protection Scheme of Single-Phase Earth Fault for Radial Distribution Systems with Distributed Generators // IEEE Transactions on Power Delivery. 33(2): 541-548. DOI: 10.1109/TPWRD.2016.2585380 (in Eng.).
- [8] Dzhezhora A.A. Determination of the width of the control zone of capacitive transducers // Later methods and aids of non-destructive testing and technical diagnostics: materials of XIII International Conference. Yalta, 2006. P. 29-31.
- [9] Dzhezhora A.A. Mirror-symmetrical measuring capacitors // Reports of the National academy of science of Belarus. Vol. 50, N 4. P. 110-114.
- [10] Bessonov: Theoretical Basics of Electrical Engineering. M.: Higher School, 1967. 775 p.
- [11] Janusz Turowski. Obliczenia elektromagnetyczne elementow maszyn i urzadzen elektrycznych // Wydawnictwa Naukowo-Techniczne. Warszawa, 1982. 200 p.
- [12] Grinberg G.A. Selected questions on mathematical theory of electrical and magnetic phenomena. M.: AN SSSR, 1948.
- [13] Matis I.G. Capacitive transducers for non-destructive testing. Riga: Zinatne, 1982. 302 p.
- [14] Electro-physical measurement moisture: pat. GB, GIN N 1136826, 1967/ Rowntree and Co.
- [15] Capacitance of capacitor with comb-shaped electrodes / V.M. Kurbatov [oth.] // Elektrichestvo. 1975. N 6. P. 84-86.
- [16] Calculation of partial capacitance in three-electrode symmetrical capacitive transducers / M.G. Strunskiy [oth.] // Elektrichestvo. 1978. N 6. p. 33-38.
- [17] Calculation of partial capacitance in capacitive transducers taking into account cross-sectional shape of controlled conductor / M.G. Strunskiy [oth.] // Elektrichestvo. 1980. N 9. P. 25-32.
- [18] Measuring relative positions using capacitive transducers: pat. N 2046920, 1980 / Gerard Charies Camille/
- [19] Netushil A.V. Potential field calculations // Works of MPEI. 1951. N 9. P. 3-25.
- [20] Matis I.G. Calculation of the electric field of a capacitor with one-sided arrangement of electrodes // Izv. akad. nauk latv SSR. Ser. fiz.-tekhn. nauk. 1965. N 5. P. 77-91.
- [21] On the prospects for the use of capacitive sensors / A.L. Grokholskiy [oth.] // Avtometriya. 1967. N 1. P. 17-23.
- [22] Alexandre Nassif (2018) An Analytical Assessment of Feeder Overcurrent Protection with Large Penetration of Distributed Energy Resources // IEEE Transactions on Industry Applications. Vol. PP, Issue 99. DOI: 10.1109/TIA.2018.2810260
- [23] Rebizanta W., Solaka K., Brusilowicza B., Benysek B., Kempskib A., Rusiński J. (2018) Coordination of overcurrent protection relays in networks with superconducting fault current limiters. Vol. 95, February 2018. P. 307-314. <https://doi.org/10.1016/j.ijepes.2017.08.021>.
- [24] Dzhezhora A.A. Mathematical model of capacitive sensor for monitoring physical anisotropy // Information transducers and sensors in measurement, monitoring and control systems: materials of XVI International Science and Technology Conference "Datchik-2004". Sudak, 2004. P. 91-92.
- [25] Grigorishin I.L. Analytical calculation of potential in coplanar shielded electrode system / Ves. nats. akadem. nauk Belorussii. Ser. fiz.-tekhn. nauk. 2005. N 2. P. 96-99.

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