RT&A, No 3 (86)
Volume 20, September 2025

RELIABILITY OF ELECTRICAL MACHINES VIA POWER LOSS MODELING IN MATLAB

Sara Alimamedova[1], Saida Kerimova[2]

•

Azerbaijan State Oil and Industry University, Baku, Azerbaijan
[1] sara_elimemmedova@mail.ru , [2] saidakerimova77@mail.ru

Abstract

The article discusses a reliable mathematical approach to calculating power losses in electrical equipment, which is a critical component in the design, analysis, and optimization of electric power systems. Ensuring accurate loss estimation requires detailed modeling of equipment parameters such as rated power, voltage, current, resistance, and material properties that influence energy dissipation. For alternating current systems, it is particularly important to consider the interaction of active and reactive components, as well as the losses occurring in conductors, magnetic circuits, and other elements. The application of proven mathematical models enables engineers to evaluate system efficiency and operational stability under different scenarios. MATLAB tools and algorithms play a key role in automating these calculations, allowing for precise simulations across a wide range of load conditions, voltage levels, and equipment configurations. This not only improves the accuracy of loss assessments but also supports optimization of design parameters to ensure long-term reliability, energy efficiency, and cost-effectiveness of electrical machines and systems.

Keywords: power loss, energy transfer, electric equipment, active resistance

I. Introduction

Modeling the calculation of power loss in electrical equipment is an important tool for designing and optimizing electric power systems. This allows engineers to analyze equipment performance, determine efficiency, and estimate energy costs [1]. To this end, it is necessary to consider the following steps and methods for modeling the calculation of power loss:

1. Determination of equipment parameters, which include equipment characteristics such as rated power, voltage, current, resistance and other parameters that may affect power loss.

2. Using mathematical models. For each type of equipment, there are mathematical models that describe its operation. For example, models based on loss formulas that take into account resistance, frequency, length, and current can be used for wires and cables.

3. Accounting for other sources of losses. In addition to losses in wires, it is necessary to take into account losses in transformers, voltage regulators, contact connections, etc.

4. Verification and analysis of the results. After performing the calculations, it is necessary to analyze the results obtained and check them for compliance with the requirements of system efficiency and reliability.

5. Optimization. Based on the simulation results, various ways can be proposed to optimize the system in order to reduce power losses, such as changing the wire cross-section, choosing more efficient transformers, improving the quality of connections, etc.

It is important to note that the accuracy of the simulation depends on the accuracy of the entered data and the correct choice of mathematical models for each component of the system. The transfer of energy from an active two-pole to a passive two-pole in the conditions of an alternator and an active reactance can be considered from the point of view of the active and reactive power components [2-4]. When transferring energy from an active two-pole to a passive two-pole, taking into account the reactants, the following cases are possible:

- If the passive two-pole is purely active (there is no reactance), then all active power will be transmitted unchanged, and no reactive power will be transmitted.
- If a passive two-pole has both active and reactive resistance, then the loss of power to overcome the reactance will be taken into account when transmitting power. This can lead to a partial loss of energy to overcome the reactance and, consequently, a decrease in the useful active power reaching the passive two-pole.

II. Formulation of the problem

In general, for a more accurate analysis of energy transfer between active and passive bipolar conductors in an AC system with active reactance, it is essential to consider all active and reactive components, as well as power losses in the conductors and other elements of the system.

Let us examine the process of energy transfer from an active bipolar source to a passive bipolar load under the conditions of an alternating current generator with active reactance (Figure 1). In Figure 1, M denotes a motor whose rotational speed remains constant, and G is an AC generator. In expression (1), $Z_0 = ze^{j\phi_0}$- represents the internal impedance of the generator, and , $Z_0 = ze^{j\phi}$ is the load impedance.

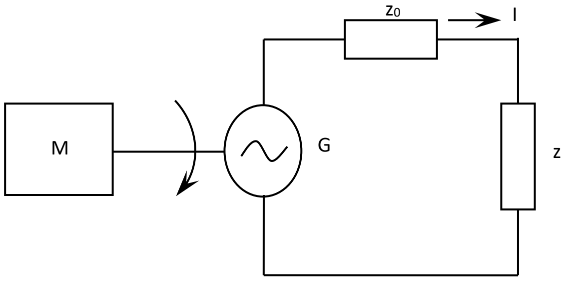

Figure 1. *Connection diagram of the alternator to te active reactance*

Based on Figure 1, the following parameters of the electrical circuit are defined: I-the root mean square (RMS) value of the current flowing through the circuit, S1-the apparent power output by the generator, U2- the RMS voltage across the load impedance, S2-the apparent power at the load, P1-the active power output by the generator, P2-the active power at the load,η-the efficiency of the system, cosφ- the power factor.

$$\left.\begin{aligned}
&I = \frac{E}{\sqrt{z_0^2+z^2+2z_0 z\cos(\varphi-\varphi_0)}}\\
&S_1 = EI = \frac{E^2}{\sqrt{z_0^2+z^2+2z_0 z\cos(\varphi-\varphi_0)}}\\
&S_2 = I^2 z = \frac{E^2 z}{z_0^2+z^2+2z_0 z\cos(\varphi-\varphi_0)}\\
&U_2 = Iz = \frac{E^2 z\cos\varphi}{\sqrt{z_0^2+z^2+2z_0 z\cos(\varphi-\varphi_0)}}\\
&P_1 = I^2(z\cos\varphi + z_0\cos\varphi) = \frac{E^2(z\cos\varphi+z_0\cos\varphi)}{z_0^2+z^2+2z_0 z\cos(\varphi-\varphi_0)}\\
&\eta = \frac{P_2}{P_1} = \frac{z\cos\varphi}{z\cos\varphi+z_0\cos\varphi} = \frac{R}{R+r_0}\\
&\cos\psi = \frac{P_1}{S_1} = \frac{z\cos\varphi+z_0\cos\varphi}{\sqrt{z_0^2+z^2+2z_0 z\cos(\varphi-\varphi_0)}}
\end{aligned}\right\} \qquad (1)$$

As basic values:

$$I_b = \frac{E}{z_0};\ S_b = P_b = \frac{E^2}{z_0};\ U_b = E$$

then these expressions can be written in a system of relative units:

$$I* = \frac{I}{I_b};\ S^* = \frac{S}{S_b};\ U* = \frac{U}{E}$$

$$\left.\begin{aligned}
I* = S_1^* &= \frac{1}{\sqrt{1+(z/z_0)^2+2(z/z_0)\cos(\varphi-\varphi_0)}}\\
U_2^* &= \frac{z/z_0}{\sqrt{1+(z/z_0)^2+2(z/z_0)\cos(\varphi-\varphi_0)}}\\
P_1^* &= \frac{z/z_0 \cos\varphi+\cos\varphi_0}{\sqrt{1+(z/z_0)^2+2(z/z_0)\cos(\varphi-\varphi_0)}}\\
P_2^* &= \frac{z/z_0 \cos\varphi}{\sqrt{1+(z/z_0)^2+2(z/z_0)\cos(\varphi-\varphi_0)}}\\
\cos\psi &= \frac{z/z_0 \cos\varphi+\cos\varphi_0}{\sqrt{1+(z/z_0)^2+2(z/z_0)\cos(\varphi-\varphi_0)}}\\
\eta &= \frac{R/r_0}{R/r_0+1}
\end{aligned}\right\} \quad (2)$$

The dependences of these expressions on the current can be written in a relative system of units as follows:

$$\left.\begin{aligned}
&S_1^* = I*;\ U_2^* = I*z/z_0\\
&S_2^* = I^{*2} z/z_0;\ P_2^* = I^{*2} z/z_0 \cos\varphi\\
&P_1^* = I^{*2} z/z_0 \cos\varphi + \cos\varphi_0\\
&\eta = \frac{z/z_0 \cos\varphi}{z/z_0\cos\varphi+\cos\varphi_0}
\end{aligned}\right\} \quad (3)$$

The analysis of expressions (1) and (2) shows that when $z/z_0 = 1$ the total and active forces applied to the load resistance have a maximum value:

$$\left.\begin{aligned}
S_2^* &= S_{2max}^{*\frac{1}{2[(1+\cos(\varphi-\varphi_0))]}}\\
P_2^* &= P_{2max}^{*\frac{\cos\varphi}{2[(1+\cos(\varphi-\varphi_0))]}}\}
\end{aligned}\right\} \quad (4)$$

The analysis of expression (4) shows that as the difference φ-φ0 increases, the maximum value of the total power (S_{2max}^*) in the load resistance increases [5]. When φ=-φ0 , the maximum value of the active power on the load resistance takes on its maximum value. On the other hand, the dependence of ($P_{2\max}^*$) on φ0 (Figure 4) can be determined using the following expression:

$$P_{2max}^{*\frac{\cos\varphi}{2[(1+\cos(\varphi-\varphi_0))]}}$$

If φ=-φ0 , then

$$P_{2max}^{*\frac{\cos\varphi}{2[(1+\cos 2\varphi_0)]}\frac{1}{4\cos\varphi_0}}$$

If φ0=0, we get $P_{2max}^{*\frac{1}{4}}$.

In AC circuits, resonance occurs when the inductive and capacitive reactance's cancel each other out at a specific frequency. At resonance, the circuit is purely resistive, and energy transfer becomes efficient. This condition could be relevant when trying to optimize energy transfer between the active and passive bipolar.

The issue of energy transfers between an active bipolar and a passive bipolar in the presence of active reactance in an AC system revolves around the reactive power and the phase relationship between the voltage and current [6-8]. If the reactance is mismatched, energy transfer can become inefficient, with a significant portion of the energy oscillating between the generator and the load without performing useful work. Proper impedance matching and managing the reactance of both the generator and the load are key to ensuring efficient energy transfer in such systems.

We will use expressions (2) and (3) to construct dependencies of their parameters in the circuit described in Figure 1 on the relative value of the load resistance and the relative value of the current (I*).

AC electric drives have steel, copper and mechanical losses. Losses on individual circuit elements depend on the circuit parameters, the load price, and the nature and voltage of the network. Losses in an electrical circuit depend on several factors:

- **Circuit parameters** (resistance, inductance, capacitance) cause energy dissipation and influence reactive power losses.
- **Load characteristics** (resistive or reactive loads, power factor) determine how much energy is lost as heat or stored and returned as reactive power.
- **Nature and voltage of the network** (AC or DC, high or low voltage) influence resistive losses, reactive losses, and efficiency in energy transmission.

Minimizing losses requires careful consideration of these factors, such as optimizing the voltage levels, ensuring proper impedance matching, and managing the nature of the load to reduce reactive power consumption [9-11].

In this case, we can write:

$$\Delta P = f(I, U, Z) \tag{5}$$

where ΔP- losses in the circuit, I, U - current and mains voltage flowing through the circuit, respectively, and Z - total resistance of the circuit. Since this is the total resistance of the circuit $Z = \frac{U}{I}$, expression (5) can be written as:

$$\Delta P = f(U, I, Z) = \Delta P_P + \Delta P_m = k_1 U^2 + k_{\ 2} I^2 \tag{6}$$

here ΔP_P- loss of steel in the unit.The price of this varies proportionally to the square of the voltage in the unsaturated steel under constant frequency conditions. ΔP_m-copper losses of the device.

Losses in the entire device change if the power factor changes when the active load of the device does not change.

To find the degree of change in load loss depending on the power factor, we can write:

$$\frac{P_m}{P_{mn}} = \frac{kI_a^2 \cos^2 \phi}{kI_a^2 \cos^2 \phi_n} = \frac{\cos^2 \phi}{\cos^2 \phi_n} \tag{7}$$

Of great interest is how losses in electrical installations change when the mains voltage changes. Using the above expression (5), we can write down the relative values:

$$\Delta P = \Delta P_P + \Delta P_m = k_1 U_n^2 U^2 + k_2 I_n^2 I^2$$

To determine coefficients k_1 and k_2:

$$\Delta P_P = k_1 U_n^2 U^2$$

From the last expression, where U=1, we get:

$$\Delta P_{pn} = k_1 U_n^2 \quad \text{or} \quad k_1 = \frac{P_{pn}}{U_n^2}$$

$$k_2 = \frac{P_{pn}}{I_n^2}$$

Where ΔP_{pn}- steel loss at rated voltage, and ΔP_{mn} - copper loss at rated current. If we write down and take into account the expressions found for the coefficients k_1 and k_2 instead of them in the general loss expression, then

$$I = \frac{\beta \cos \phi_n}{U \cos \phi}; \Delta P = \Delta P_{pn} U^2 + \Delta P_{mn} I^2 = P_{pn} U^2 + P_{mn} \cos^2 \phi_n \frac{\beta}{U^2 \cos^2 \phi}$$

Here we take

$$a = \Delta P_{pn}; \ b = \Delta P_{pn} \cos^2 \phi_n \ , \tag{8}$$

and we get:

$$\Delta P = aU^2 + b \frac{\beta}{U^2 \cos^2 \phi} \tag{9}$$

III. Problem solution

Below is the MATLAB code to calculate and plot the power factor for a constant active load, considering different voltage levels and calculating the corresponding apparent power and power factor [12].

If we take the first-order derivative of this expression with respect to voltage and make it equal to zero, we will find the voltage expression for the case of minimal losses:

$$\frac{d\Delta P}{dU} = 2aU = \frac{2b\beta^2}{U^3 \cos^2 \phi} = 0; \quad U = \sqrt[4]{\frac{b\beta^2}{a \cos^2 \phi}} \tag{10}$$

From the last expression, it can be concluded that the lower the load factor, the lower the minimum current received at such a low voltage [13-15]. As can be seen from the expression minimum current, the price of the relative voltage obtained also depends on the power factor of the unit. As the power factor of the device increases, the minimum resistance shifts towards decreasing voltage.

Let's consider the effect of voltage changes in an asynchronous motor on motor losses using the above. It is known that in an asynchronous motor, the main losses are no-load operating losses (mainly steel losses) and copper losses [16-18]. The remaining losses can be discarded, as they are relatively small. Then we can write:

$$\Delta P_{mwh} = \Delta P_0 + \Delta P_m = k_1 U^2 + k_2 I^2$$

If we divide both parts of this expression by k=2, we get:

$$\Delta P = \frac{\Delta P_{mwh}}{k_2} = \frac{k_1}{k_2} U^2 + I^2 = kU^2 + I^2$$

the relative loss

$$\Delta P = (k + b)U^2 + \frac{a}{U} \tag{11}$$

To model how the losses in electrical installations change when the mains voltage changes, we need to consider the basic formula for losses, which primarily come from the **resistive losses** (I^2R losses) in the conductors and transformers. These losses are a function of the current ($\bar{I}$) and the resistance ($\bar{R}$)of the components. When the mains voltage changes, the current also changes, which in turn affects the losses (Figure 2).

In an asynchronous (induction) motor, the losses are mainly due to the following factors:

- Stator copper losses: Resistive losses in the stator winding.
- Rotor copper losses: Resistive losses in the rotor winding.
- Core losses (iron losses, usually represented as a function of the motor's voltage and frequency).
- Mechanical losses: Losses due to friction, windage, and other moving parts.

When the voltage changes, it impacts the current, which in turn affects the copper losses and other parameters. An increase in voltage will generally decrease the current for a fixed power output, leading to a reduction in copper losses. However, core losses in the motor typically depend on the applied voltage and the frequency of the motor [19-21].

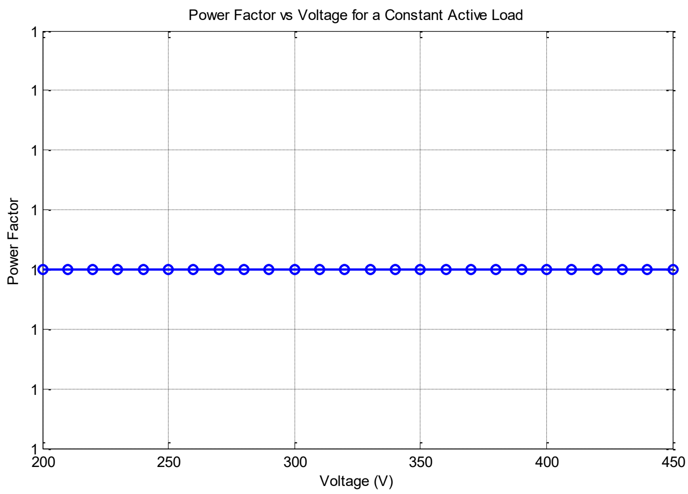

Figure 2. *Power factor vs voltage for a constant active load*

The Figure 3 shows how each type of loss varies with voltage. As the voltage increases, both the stator and rotor copper losses will decrease, while core losses will likely increase. The total losses will decrease for lower voltages but will show a relatively minor increase due to core losses at higher voltages. This simulation provides a basic model to understand how changes in voltage impact the various losses in an asynchronous motor. In practice, other factors, such as temperature and speed, might also influence these losses.

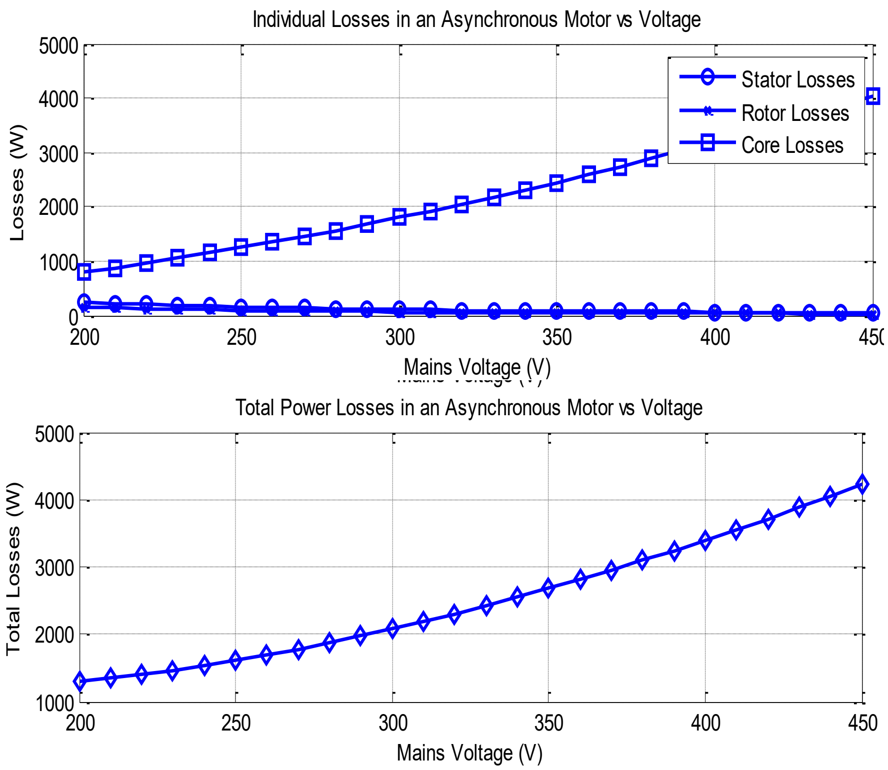

Figure 3. *Losses in an Asynchronous Motor vs Voltage*

The following MATLAB code simulates how the resistive losses change when the mains voltage changes (figure 4).

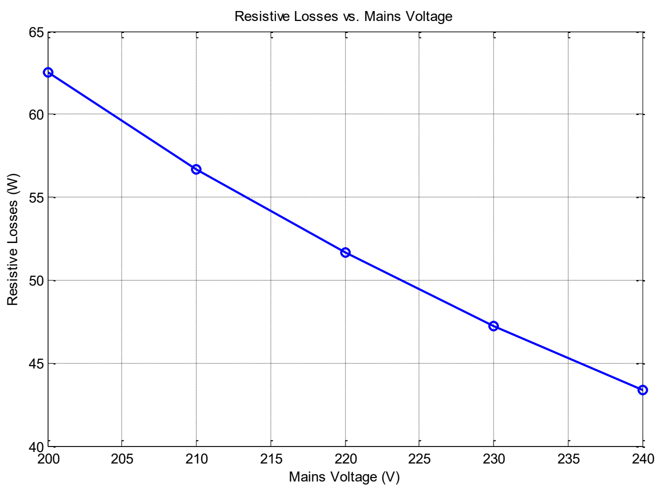

Figure 4. *Resistive losses vs Mains Voltage*

- As the voltage increases, the current decreases, leading to a decrease in resistive losses.
- As the voltage decreases, the current increases, leading to an increase in resistive losses.

This will give you a clear visualization of how the resistive losses in an electrical installation depend on the mains voltage [22]. You can modify the P and R parameters according to your specific system requirements. The plot will typically show a decreasing curve for losses as the voltage increases (since the current decreases for constant power), demonstrating how the installation efficiency improves with higher voltage.

Simulating the calculation of power loss in synchronous machine, the losses can be broadly categorized as:

1. Stator losses: Copper losses in the stator winding
2. Rotor losses: Copper losses in the rotor winding
3. Core losses: Losses due to eddy currents and hysteresis in the magnetic core.
4. Mechanical losses: Friction and windage losses in the bearings and other moving parts.
5. Stray load losses: Losses due to stray magnetic fluxes and other minor factors.

In the following simulation, we will assume some typical values for a synchronous machine, and calculate the losses based on different operating conditions (such as speed, load, and voltage).

As the load factor increases, the copper losses in both the stator and rotor increase, as they depend on the current. Core losses and mechanical losses also increase with load, though core losses may not scale linearly in some cases (depending on the machine design). The plot will show a clear increase in losses as the machine load increases [24].

This simulation provides a basic model of power loss calculation in synchronous machines, with the assumption that we have some simple loss models for core and mechanical losses. The actual losses in a real machine can be more complex and depend on many other factors, such as temperature, operating conditions, and machine design specifics.

The advantages of mathematical analysis and algorithms in MATLAB for determining losses in various electrical machines and equipment are in several important aspects:

1. Accuracy and detail of calculations. Mathematical analysis allows accurate modeling of processes in electrical machines, such as asynchronous and synchronous machines, transformers, and other devices. This analysis includes both basic elements (e.g. currents, voltage, active and reactive power) and more complex losses such as:

- Copper losses (I^2R) are losses in the windings related to the resistance of the conductors.
- Nuclear losses are losses associated with magnetic saturation and eddy currents in cores.
- Mechanical losses - losses related to friction in bearings and air resistance (wind resistance).
- Strange losses - loss of energy due to imperfect operating conditions of the device.

In MATLAB, you can accurately account for all these elements in calculations using various mathematical models and approaches, such as:

- Circuit analysis using methods of electrical circuit theory (Kirchhoff methods, substitution circuit methods).
- Elements of thermodynamics and electromagnetic theories for modeling losses in magnetic materials.

2. Flexibility and adaptability. MATLAB provides the ability to flexibly customize models and algorithms for various types of electrical machines and equipment. For example:

- For asynchronous machines, it is possible to take into account the change in rotor current depending on sliding and different operating modes.
- For synchronous machines, it is possible to simulate the dependence of losses on the angle of the rotor position and the magnetic field.
- For transformers and other devices, the effects of magnetic field pulsation, asymmetry, and other specific operating features can be taken into account.

The advantage is the ability to easily change model parameters and get results for different operating modes.

3. Visualization of results. MATLAB provides powerful data visualization tools that help to better understand the behavior of electrical machines and equipment under various operating conditions. For example:

• Graphs of loss dependence on load, voltage, frequency or other parameters.

• Contour loss maps depending on various factors.

• 3D graphics to display the distribution of magnetic fields and temperature fields in the machine (Figure 5). This helps not only to analyze losses, but also to identify optimal operating modes to reduce losses and increase work efficiency.

4. Automation of calculations and repeatability. MATLAB algorithms can be used to automate the calculation of losses in electrical machines. This is especially useful when it is necessary to perform a large number of calculations for various operating scenarios (for example, when designing new machines or optimizing existing ones). An example would be using scripts to automatically calculate losses at different load and voltage levels, as well as to perform calculations using different types of windings or materials [25-26].

5. Optimization and search for the best solutions. MATLAB provides optimization tools, which allows not only to estimate losses, but also to find optimal parameters of machines and equipment, minimizing losses. For example:

• Optimization of design parameters (e.g. conductor cross-section, core materials) to minimize losses.

• Using optimization methods to select the operating modes of the equipment (for example, rotational speeds for asynchronous machines) with minimal losses.

6. Simulation of real-world operating conditions. MATLAB allows you to create accurate models of the operation of electrical machines in real conditions, taking into account such parameters as:

• Imperfections in the operation of devices (for example, losses due to overload, fluctuations in the network, etc.).

• The effect of temperature changes on the resistance of materials and, as a result, on losses.

• Asymmetric loads and parameter mismatches in three-phase systems.

This allows for more accurate and practical results, which is especially important for research and design tasks.

7. Integration with other systems. MATLAB integrates seamlessly with other systems and tools to enhance analysis and simulation capabilities. For example:

• Using MATLAB to create models with blocks, simulate the operation of electrical machines in real time, and analyze dynamic processes.

• Integration with laboratory systems for collecting and processing real-world data (for example, through interfaces with microcontrollers or measuring systems). Using MATLAB for mathematical analysis and creation of algorithms for calculating losses in electrical machines and equipment has many advantages, including accuracy of calculations, flexibility, visualization of results, the possibility of optimization and integration with other tools. This allows not only to conduct effective analysis, but also to make informed decisions in the design and operation of electrical devices.

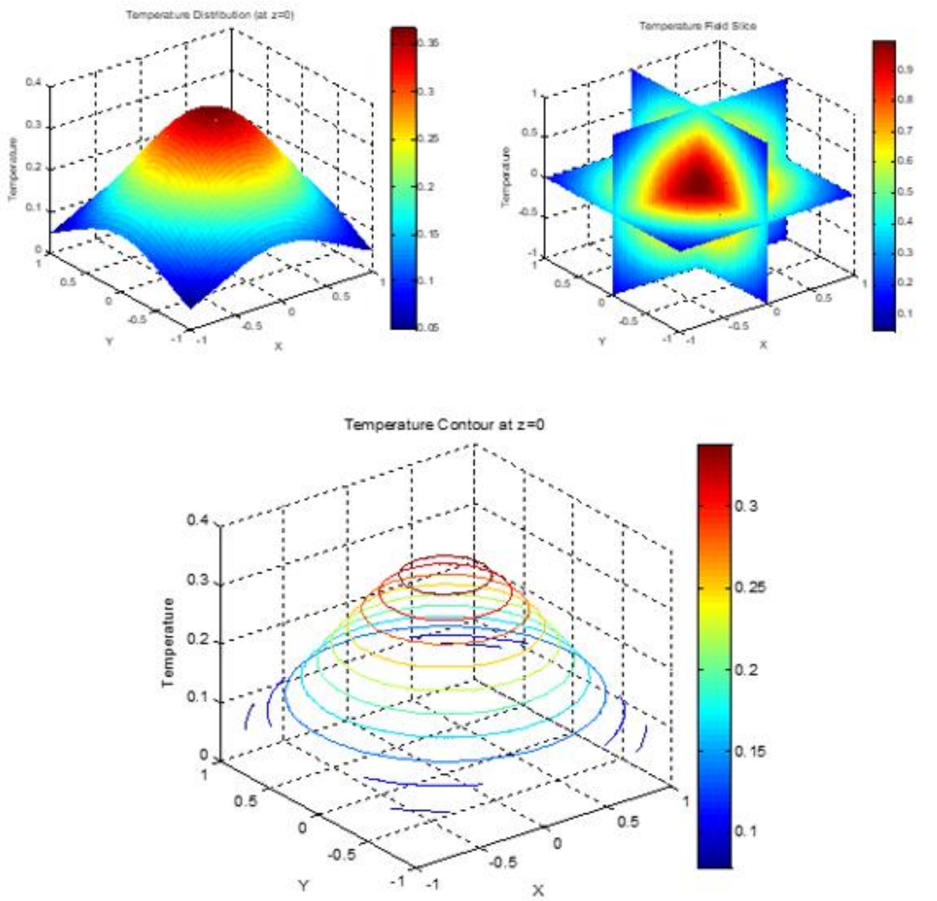

Figure 5. *Distribution of magnetic fields and temperature fields in the machine*

IV. Conclusions

1. Mathematical analysis of the calculation of power loss in electrical equipment, which is an important aspect for the design and optimization of electric power systems, allows engineers to analyze equipment performance, determine efficiency and estimate energy costs. To this end, it is necessary to consider methods for modeling the calculation of power loss, determining equipment parameters that include equipment characteristics such as rated power, voltage, current, resistance and other parameters that may affect power loss, and using mathematical models.

2. Using MATLAB algorithms, it is possible to automate the processes of calculating losses in electrical machines. This is especially useful when it is necessary to perform a large number of calculations for various operating scenarios (for example, when designing new machines or optimizing existing ones).

3. Mathematical analysis allows accurate modeling of processes in electrical machines, such as asynchronous and synchronous machines, transformers, and other devices. This analysis includes both basic elements (for example, currents, voltage, active and reactive power) and more complex losses, such as losses in windings related to conductor resistance, losses related to magnetic saturation and eddy currents in cores, losses related to friction in bearings and resistance air resistance (wind resistance), loss of energy due to imperfect operating conditions of the device.

References

[1] Khanahmedova, S. A., Ismayilova, G. G., & Mufidzade, N. A. (2024). Analysis of the method of calculating the conversion circuit based on generalized functions. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, 16(3), 120–126.

[2] Khanahmedova, S. A., Kerimova, S. M., & Alimamedova, S. J. (2022). Mathematical modeling of the operation of a three-phase power transformer at low voltage quality. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, 14(4), 225–232.

[3] Khanahmedova, S. A. (2023). Investigation of some electrical circuits using simulation in MATLAB/Simulink. *Bulletin of Science*, 2(59), Vol. 1, 125–129. Tolyatti, Russia.

[4] Hasanov, Z. A., & Khanahmedova, S. A. (2022). *Power electronics and electrical drive*. Baku, Azerbaijan: Azerbaijan State Oil and Industry University Publishing House, pp. 5–132.

[5] Khanahmedova, S. A. (2024). Some issues of increasing the efficiency of electric machines. *Przegląd Elektrotechniczny*, 9(4), 171–173.

[6] Khanahmedova, S. A., Ismayilova, G. G., & Mufidzade, N. A. (2024). Analysis of the method of calculating the conversion circuit based on generalized functions. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, 16(3), 120–126.

[7] Piriyeva, N. M., & Kerimzade, G. S. (2023). Methods for increasing electromagnetic efficiency in induction levitator. *Przegląd Elektrotechniczny*. Warszawa: SIGMA-NOT, October, 192–195.

[8] Piriyeva, N. M., & Kerimzade, G. S. (2023). Electromagnetic efficiency in induction levitators and ways to improve it. *Przegląd Elektrotechniczny*, NR 06/2023, Warszawa, 204–207.

[9] Piriyeva, N. M., & Kerimzade, G. S. (2023). Mathematical model for the calculation of electrical devices based on induction levitators. *International Journal on Technical and Physical Problems of Engineering (IJTPE)*, 15(2), 274–280.

[10] Khanahmedova, S. A. (2025). Mathematical analysis of the mechanical part of the design scheme of the electric drive of a hybrid electric machine. *Reliability: Theory & Applications (RT&A)*, 20(1), 1061–1069.

[11] Khanahmedova, S. A. (2024). Some issues of increasing the efficiency of electric machines. *Przegląd Elektrotechniczny*, 100(9), 171–173.

[12] Osman, T., & Mohammad, S. (2006). Power distribution asset management. In *2006 IEEE Power Engineering Society General Meeting* (pp. 7–14). https://doi.org/10.1109/PES.2006.17092342

[13] Renani, Y. K., Ehsan, M., & Shahidehpour, M. (2018). Optimal transactive market operations with distribution system operators. *IEEE Transactions on Smart Grid*, 9(6), 6692–6701. https://doi.org/10.1109/TSG.2017.27185463

[14] Ghasemi, H., Aghaei, J., Gharehpetian, G. B., & Safdarian, A. (2019). MILP model for integrated expansion planning of multi-carrier active energy systems. *IET Generation, Transmission & Distribution*, 13(7), 1177–1189. https://doi.org/10.1049/iet-gtd.2018.63284

[15] Baydar, B., Gozde, H., Taplamacioglu, M. C., & Kucuk, A. O. (2019). Resilient optimal power flow with evolutionary computation methods: short survey. In N. Mahdavi Tabatabaei, S. Najafi Ravadanegh, & N. Bizon (Eds.), *Power Systems Resilience* (pp. 163–189). Cham: Springer. https://doi.org/10.1007/978-3-319-94442-5_75

[16] Koziel, S., Landeros Rojas, A., & Moskwa, S. (2018). Power loss reduction through distribution network reconfiguration using feasibility-preserving simulated annealing. In *2018 19th International Scientific Conference on Electric Power Engineering (EPE)* (pp. 1–5). https://doi.org/10.1109/EPE.2018.83960166

[17] Ilham Rahimli, Rashida Karimova, Najiba Piriyeva. Development of a Two-Parameter Inductive Sensor for use in Digital Program Control Systems for Machine Tools. PRZEGLAD Elektrotechniczny ISSN 0033-2097, R.100 NR 08/2024. WARSZAWA. pp.194-197.

[18] Zhang, X., Shahidehpour, M., Alabdulwahab, A., & Abusorrah, A. (2015). Optimal expansion planning of energy hub with multiple energy infrastructures. *IEEE Transactions on Smart Grid*, 6(5), 2302–2311. https://doi.org/10.1109/TSG.2015.23906408

[19] . I.M.Marufov, N.M.Piriyeva, N.S.Mammadov, Sh. Ismayilova. (2024) Calculation of induction levitation vertical axis wind generator-turbine system parameters, levitation and influence loop. Warszawa PRZEGLĄD ELEKTROTECHNICZNY, R. 100 NR 2/2024 pp.135-139.

[20] N.M.Piriyeva, G.S. Kerimzade. (2024) Systematization of levitation equations for electrical devices with levitation elements. PRZEGLAD Elektrotechniczny R.100 NR 08/2024. Warszawa. pp.175-177

[21] N.M.Piriyeva, Kerimzade G.S., Mamedova G.V. (2023) Issues of design of electrical devices with levitation elements. International Journal on "Technical and Physical Problems of Engineering" IJTPE Rumıniya Issue 56, Vol. 15 No 3. s.120-125

[22] S.V. Rzayeva, N.A. Ganiyeva N.M.Piriyeva. (2024) Modern approaches to electrical equipment diagnostics. İnternational Journal on "Technical and Physical Problems of Engineering" (IJTPE) - Issue 58, Volume 16, Number 1, March 2024 (Serial No: 0058-1601-0324), pp.182-189

[23] Aliyev, N., Ahmedov, E., Khanahmedova, S., & Rzayeva, S. (2023). Synthesis of the Exact Parameters of the Electromagnetic Brake of a Wind Electric Installation. *Przegląd Elektrotechniczny*, *2023*(10).

[24] Safiyev, Elshad, Ilham Rahimli, and Nijat Mammadov. "Method of qualitative impregnation of electric motor windings." Przegląd Elektrotechniczny 8 (2024).

[25] Nijat, Mammadov. "Selection of the type of electric generators for a wind electric installation." Universum: технические науки 9-5 (102) (2022): 65-67.

[26] Mammadov, N., Rzayeva, S., & Ganiyeva, N. (2023). Analysis of synchronized asynchronous generator for a wind electric installation. *Przeglad Elektrotechniczny*, *99*(5).