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Study on Measurement of Electromagnetic Compatibility in the Transmission Lines and Substations of Erdenet Mining Corporation

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Abstract - Electromagnetic compatibility (EMC) is an understanding of modern research, that research to summarize variety electromagnetic phenomena such as over voltage, radio noise, network voltage fluctuation, ground affect. It is essential to research of electromagnetic state and compatibility during the operation of the transmission lines and substations which is the largest electrical power system, and to take measures to protect the equipment, that exceeding the maximum permissible level of electromagnetic compatibility parameters. [1] The 220 kV, 110 kV, and 35 kV power grids and substations of Erdenet Industrial Power Plant, a major electricity consumer in Mongolia, were selected as the research objects. Electric and magnetic field measurements were conducted to determine the electromagnetic environment of the power supply system of the Erdenet plant, overhead power lines, and substations, and their compatibility. The measurements were performed using 4 types of instruments, HI-3603 SURVEY METER and -AARONIA SPECTRAN, which met the standards. A total of 3,484 measurements were taken at 41 points. The measurement results were processed using MATLAB and COMSOL software. The measurement and simulation results have been evaluated against the International Standard IEC 61000. he discrepancy between the simulated and measured values was within 3%, confirming that the developed simulation models are accurate and can be reliably used for further EMC studies.

Keywords - Electromagnetic compatibility, transmission line, substation, measurement, standard, MATLAB and COMSOL software

Эрдэнэт Үйлдвэрийн Цахилгаан Дамжуулах Шугам, Дэд Станцын Цахилгаан Соронзон Нийцлийн Хэмжилтийн Судалгаа

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Хураангуй - Цахилгаан соронзон нийцтэй байдал (EMC) нь хэт хүчдэл, радио дуу чимээ, сүлжээний хүчдэлийн хэлбэлзэл, газрын нөлөөлөл гэх мэт янз бүрийн цахилгаан соронзон үзэгдлүүдийг нэгтгэн дүгнэх судалгааг орчин үеийн судалгааны ойлголт юм. Монгол улсын томоохон цахилгаан эрчим хүчний хэрэглэгч болох Эрдэнэт Үйлдвэрийн ТӨХК-ийн 220 кВ, 110кВ, 35 кВ-ийн шугам сүлжээ болон дэд станцыг судалгаа объект болгож авсан. Эрдэнэт үйлдвэрийн цахилгаан хангамжийн систем дэр Цахилгаан дамжуулах агаарын шугам, дэд станцын орчин дах цахилгаан соронзон төлөв байдал, тэдгээрийн нийцтэй байдлыг тодорхойлох зорилгоор цахилгаан ба соронзон орны хэмжилтүүдийг хийсэн. Хэмжилтүүдийг гүйцэтгэхдээ стандартыг хангасан HI-3603 SURVEY METER ба -AARONIA SPECTRAN маркийн 4 төрлийн багажаар 41 цэгт 3484 хэмжилтүүдийг хийсэн. Хэмжилтийн үр дүнг MATLAB болон COMSOL программ хангамжуудыг ашиглан боловсруулалт хийсэн болно. Хэмжилт болон симуляцийн үр дүнг Олон улсын IEC 61000 стандарттай харьцуулан үнэлгээ гаргасан болно. Хэмжилт болон симуляцийн үр дүнгийн хоорондын зөрүү 3%-иас бага байсан нь боловсруулсан симуляцийн загварууд нь өндөр найдвартай, цаашдын EMC судалгаанд ашиглах боломжтой болохыг харууллаа.

Түлхүүр үг - Цахилгаан соронзон нийцэл, цахилгаан дамжуулах шугам, дэд станц, хэмжилт, стандарт, МАТЛАБ ба Comsol программ хангамж

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I. INTRODUCTION

The development of human civilization is indistinguishably linked to the growth of energy consumption, the number of electrical equipment, and the increase in their power. Electromagnetic compatibility (EMC) is an equipment characteristic or property and is defined as " the ability of equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. [2] EMC ensures that an electronic device operates effectively in its electromagnetic environment while neither emitting nor being adversely affected by unwanted electromagnetic disturbances. Achieving EMC compliance involves two key aspects: [3]

1. Controlling Emissions: Ensuring that electromagnetic emissions from the device remain within acceptable limits to avoid interference with other devices.

2. Enhancing Immunity: Designing the system to resist interference from external electromagnetic sources.

First, There are three necessary parts to an EMC problem as illustrated in Figure 1. There must be a source of electromagnetic energy, a receiver (or victim) that cannot function properly due to the electromagnetic energy, and a path between them that couples the energy from the source to the receptor. Electromagnetic compatibility (EMC) problems are generally solved by identifying at least two of the three necessary elements and eliminating (or attenuating) one of them; these elements must always be present, though they may not be readily identifiable in every situation.

Prior EMC studies in Mongolia have mainly addressed general interference concepts or limited measurements in isolated distribution systems, lacking analysis of large interconnected or industrial supply networks. Notably, no published research has examined the EMC characteristics of Erdenet's power grid, a major industrial center serving both heavy industry and residential loads. The grid's long transmission distances, mixed load structure, and significant industrial electromagnetic noise sources create operating conditions that can intensify harmonic distortion, transient interference, and protection maloperation. Given that EMC-related issues directly affect relay performance, equipment reliability, and power quality—and that Mongolia currently lacks grid-specific EMC criteria—this study provides the first empirical assessment of EMC behavior in Erdenet's network, identifies grid-specific interference mechanisms, and proposes mitigation measures suited to Mongolian power system conditions.

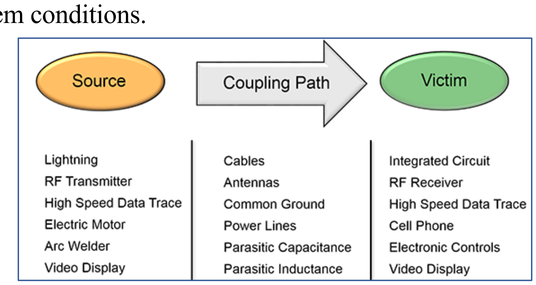

Figure 1. The three necessity parts of an EMC problem.

Potential sources of electromagnetic compatibility problems such as high voltage electromagnetic disturbance, power transmission lines, lightning, lights, electric machines, solar flares. Potential receivers include radio frequency applications, electronic circuits, appliances, human, and just about anything that utilizes or can detect electromagnetic energy. Methods of coupling electromagnetic energy from a source to a receptor fall into one of four following categories, conducted (electric current), inductively coupled (magnetic field), capacitively coupled (electric field) and radiated (electromagnetic field).

Coupling paths often utilize a complex combination of these methods making the path difficult to identify even when the source and receptor are known. There may be multiple coupling paths, and steps taken to attenuate one path may enhance another. Computing devices are getting denser, faster, more complex and more pervasive, creating new challenges for the EMC engineer. At the same time, advances in electromagnetic analysis and available design options are revolutionizing the methods used to ensure compliance with EMC requirements. Transmission and Distribution Lines: House and Outside Wiring Systems with Voltage up to 35 kV. [4]

II. OVERVIEW OF ELETCRICAL POWER SUPPLY FOR ERDENET 220/110/35 KV

Erdenet Mining Corporation SOE stands as the largest copper and molybdenum ore mining and beneficiation complex in Asia. [5] Annually, it extracts 39.6 million tons of ore, processes 37.2 million tons, and produces approximately 600,000 tons of copper concentrate and over 5,000 tons of molybdenum concentrate. The transmission system in Mongolia consists of 220 kV, 110 kV and 35 kV. The 220 kV transmission line is the route from the Russian interconnection line through the central part of Mongolia to the south, and the interconnection line from the southern part of Mongolia to China, and the other lines are almost 110 kV transmission lines. [6]

In numerous transition countries, including Mongolia, district heating is provided using a subscription-based model. This is due to several technical, financial, legal regulatory, and governance-related challenges. It is of the utmost importance to address potential challenges, such as affordability for low-income households and the need for robust regulatory frameworks, to ensure a fair and successful transition. Overall, the move towards CBB aligns with broader goals of sustainability, efficiency, and responsible resource management.

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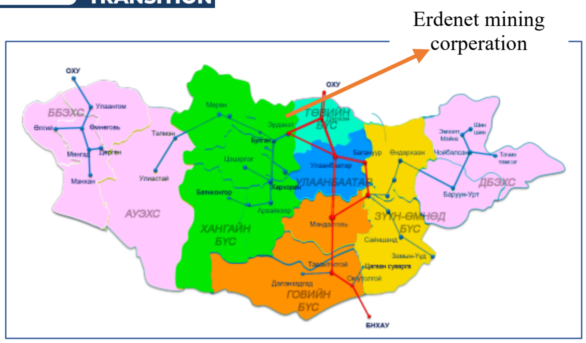

Figure 2. Transmission System diagram in Mongolia

The system classification diagram and transmission system diagram of Mongolia are shown Figure 2 (Electrical power supply of Erdenet mining corporation). The red line represents 220 kV and the blue line represents 110 kV.

III. METHODS AND MEASUREMENT OF THE EMC IN THE ERDENET MINING CORPORATION

Measurements were carried out in the 110 and 35 kV high-voltage overhead power lines, 110/6 kV and 35/6 kV transformer substations, open and closed wiring structures, workplaces located in their surroundings, electrical equipment, and work rooms of the electrical workshop administration building belonging to the “Erdenet mining corporation” SOE. Electromagnetic field effect measurements and experiments in the Erdenet “Erdenet mining corporation” SOE were performed using the following 4 types of modern instruments. It includes:

- HI-3603 survey meter
- HI-3604 survey meter
- AARONIA Spectran NF-5035
- AARONIA Spectran HF-60105

The HI-3603 VDT/VLF [7] Radiation Measurement System is designed specifically to measure electromagnetic emissions produced by video display terminals (VDT's), computer monitors, television receivers and other devices using cathode-ray tubes (CRT's) for information or data display[8]. Figure 3 illustrates the equipment named HI-3603 VDT/VLF Electromagnetic field effect measurement has been designed to permit rapid and accurate measurement of the electric and magnetic fields generated by VDT's[9].

Figure 3. HI-3603 survey meter

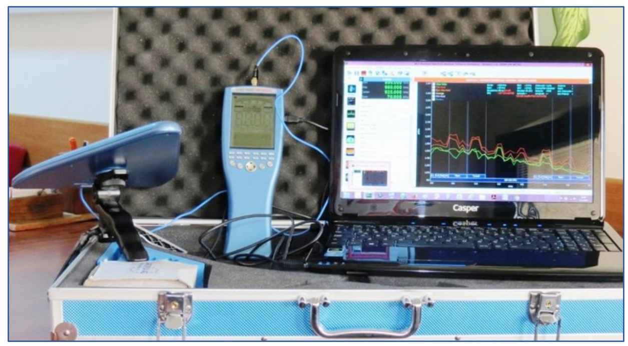

Figure 4. AARONIA Spectran HF-60105

A. Measurement of the EMC in the Erdenet

Table 1. location and repeatability of electric and magnetic field measurements [1]

№	Locations	Name of locations	Number of measurements
1	1	35/6 kV substation (Ovoot)	36
2	2	35 kV Power Transmission Line (Carrier A, B)	288
3	3	110 kV Power Transmission Line (Khyalganat A, B)	400
4	4	220 kV Power Transmission Line (203, 204)	432
5	5	35 kV Power Transmission Line (Ochistnye B)	432
6	6	Water’s pipe	32
7	7-10	110/6 kV substation (RP-1)	342
8	11-14	110/6 kV substation (RP-2)	342
9	15-22	RP-1.2 6kV substation input (Input 1-8)	300
10	23-29	Workplaces in high-voltage environments	384
11	30-34	Thermal power plant	144
12	35-38	Electrical workshop workroom	244
13	39-41	Water lifting stations	108
		Total	**3484**

As shown in Table 1, the measurements were performed using 4 types of equipment during 7 months witch April to September, HI-3603 survey meter and AARONIA Spectran, which met the standards. A total of 3,484 measurements were taken at 41 points in Erdenet mining corporation.

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Table 2. Electric and magnetic field measurements of 1 110/6/6kv, rp-1, tc substation, transformers 1 and 2 [1]

№	Measurement point	in the direction along the core of the power transformer , м	110/6/6 kV RP-1 TK substation 3604 H,A/m [1]	E, кV/m	In the direction transverse to the core of the power transformer, m	110/6/6 kV RP-1 TK substation 3604 H,A/m Height from ground to tool, m	E, кV/m
			1	1		1	1
1	110/6/6кV- RP-1. TK T-1 transformer	1	6.04	0.03	1	1.07	0.04
2		2	3.94	0.05	2	1.22	0.07
3		3	2.66	0.03	3	0.99	0.12
4		4	2.11	0.03	4	0.90	0.10
5		5	1.93	0.02	5	0.70	0.08
6	110/6/6кV-RP-1. TK T-2 transformer	1	4.53	0.46	1	1.01	0.37
7		2	4.97	0.43	2	1.05	0.09
8		3	4.11	0.39	3	0.83	0.17
9		4	2.66	0.16	4	0.68	0.15
10		5	2.16	0.11	5	0.49	0.11

B. COMSOL simulation

Across engineering, manufacturing, and scientific research, COMSOL Multiphysics® offers fully coupled multiphysics and single-physics modeling, model management, and user-friendly tools for creating simulation applications. Distribute simulation value broadly with COMSOL Compiler™ and COMSOL Server™, enabling access for design, manufacturing, labs, and customers, while specialized modules (e.g., electromagnetics, fluid flow) and CAD interfacing products extend capabilities, making complex multiphysics accessible and integrated. [10]

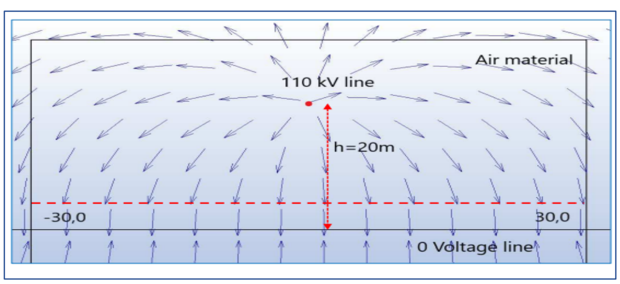

Figure 5. Distribution of the electric field at any point of the 110kV power line

Figure 5 shows that spatial distribution of electromagnetic field intensity in the Erdenet power grid, highlighting localized field concentration near substations and heavily loaded nodes.

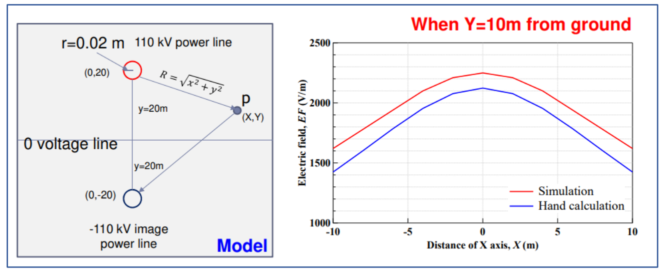

Figure 6. 110 kV line location map

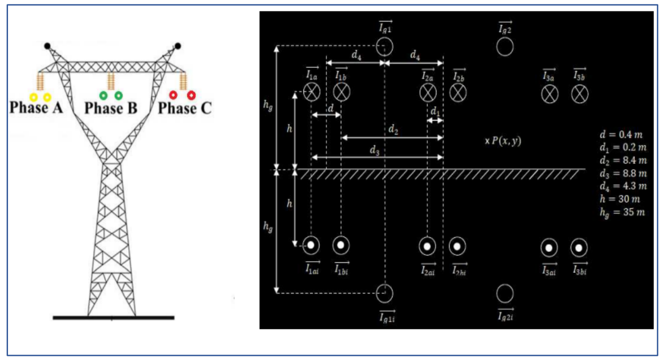

Figure 7. Calculation results of the highest electric field of 1 phase of the transmission line

As shown in Figure 7, electromagnetic field distribution under industrial load conditions, showing increased field intensity in areas with high-power nonlinear equipment.

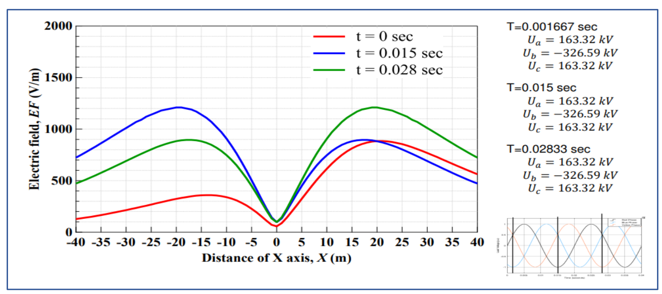

Figure 8. A double grounding conductor crossing the transmission line, a double circuit

As time changes, the charge on the transmission line must also change. As a result, the electric field is rigid and variable.[1]

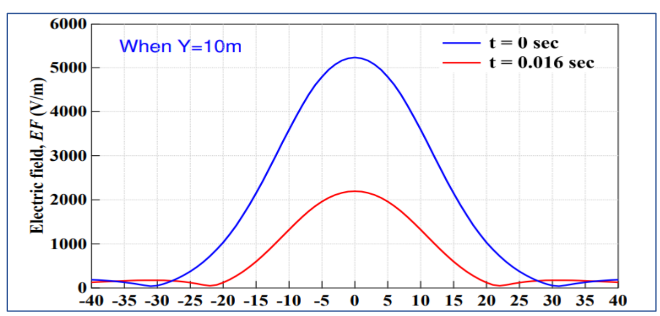

Figure 9. Electric field distribution in a single grounding conductor with a double circuit

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Results are shown in Figure 9, electromagnetic field distribution during increased load conditions, indicating peak values near feeder junctions and substation outlets approaching regulatory limits.

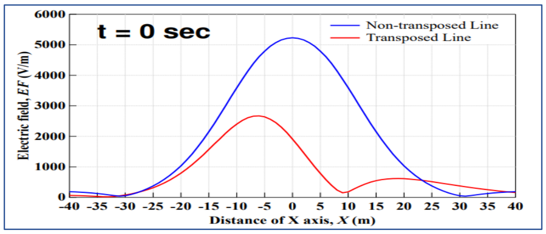

Figure 10. Electric Electric field distribution on the transmission line for time changes

Figure 10 illustrates theelectromagnetic field intensity around high-voltage equipment, illustrating the effect of cable proximity and electromagnetic coupling. Using transmission line switching reduces the power of the Electric Bed. The main calculation of the effect of electric power is carried out from the transmission line [12].The effect of the electric field depends on the magnitude of the line change, and the effect of the electric field changes abruptly. The effect of the electric field is reduced using the transfer method. Looking at the results, the electric field strength of the 400kV transmission line does not exceed the value of the standard issued by the World Health Organization (WHO) [13,14].

IV. Results and Discussion

MATLAB EMC Simulation, providing personalized assistance tailored to the research needs with clear explanations. In the process of assuring that the electronic frameworks function without any intervention, the simulations of Electromagnetic Compatibility (EMC) are most significant [11]. To simulate different factors of EMC, such as signal integrity (SI), electromagnetic susceptibility (EMS), and electromagnetic interference (EMI), MATLAB can be utilized in an efficient way. [15,16]

A. 110/6/6kV RP-1 TC substation [1]

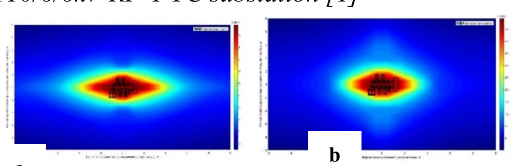

Figure 11. 110/6/6kV RP-1 TC substation, TR-1, magnetic (a) and electric (b) field construction

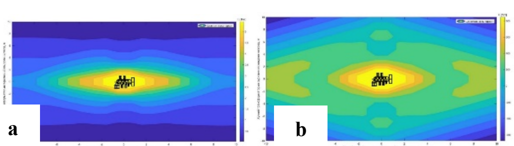

Figure 12. 110/6/6kV RP-1 TC substation, TR-2, magnetic (a) and electric (b) field construction

Figure 11 demonstrate that electromagnetic field distribution influenced by equipment layout and grounding configuration, with localized reduction in EMC safety margins. Electromagnetic field intensity in industrial zones, where measured values are closest to the permissible EMC limits as shown in Figure 12.

B. MATLAB program for constructing electric and magnetic field distribution of 35kV Ochistnye B line[1]

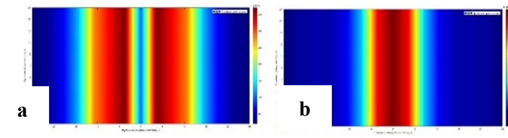

Figure 13. 35kV Ochistnye B line magnetic (a) and electric (b) field distribution map

Figure 13 shows that electromagnetic field distribution in peripheral and lightly loaded areas, demonstrating significantly lower field levels compared to industrial zones.

C. MATLAB program to create electric and magnetic field distribution of 110kV Hyalganat A and B lines[1]

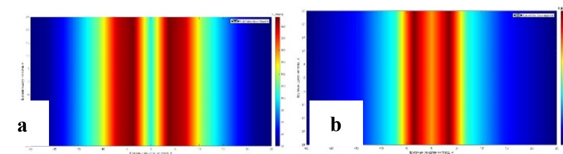

Figure 14. Map of magnetic (a) and electric (b) field distribution of 20 110 kV Khialganat A and B lines

D. MATLAB program to create electric and magnetic field distribution of 220kV UB-Erdenet line [1]

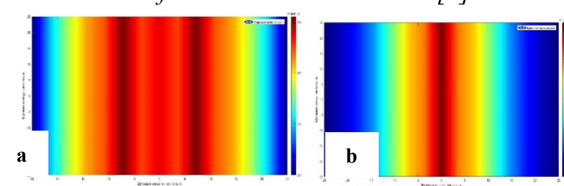

Figure 15. Magnetic (a) and electric (b) field distribution map of 220kV line 23 UB – Erdenet line

Identification of critical electromagnetic field zones within the network, indicating areas requiring targeted EMC mitigation measures in Figure 14 and 15.

V. Conclusions

Objects such as 110 kV and 35 kV substations, totaling 12 open and closed distribution facilities, electrical equipment in their environment, according to 110 kV GOK-A,B,G,D, ET-151, ET-152 TsDASH, 35 kV Kotelnaya-A,B, Ochistny-A,B TsDASH, Electrician's room located at the 110/6/6kV RP-1,2 TK substation, the 110/6/6 kV RP-1,2 TK reactor facility [1] of the Erdenet Mining Corporation SOE were selected and the electric and magnetic fields generated in their environment were studied which is shown table 1.

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The research used HI-3604 survey meter and Spectrum Analyzer NF-5035 instruments to measure low-frequency electric and magnetic fields of 50/60 Hz power transmission lines, electrical power equipment, and tools, and for industrial safety and hygiene purposes.

High-frequency electric and magnetic field measurements were performed using the HI-3603 survey meter and Aaronia SPECTRAN HF-60105 instruments[9], which are certified to ANSI Standard C95.1 for their accuracy in determining electric and magnetic fields, using technology developed by the German National Institute for Occupational Safety and Health (NIOSH) [17,18].

The measurements made with these instruments were made in the low frequency range of 0 to 1000 Hz and the high frequency range of 800 to 1000 MHz [19]. A total of 3484 measurements were taken at 41 sites, as shown in Table 1.

According to the results of the study, as can be seen from the graphs the results of low-frequency electric and magnetic field measurements on the 35 kV high-voltage overhead power lines: Ochistka-A, B, Karyer-A, B, the permissible electric field strength in the environment of high-voltage overhead power lines is 0.5 kV/m, but since people do not permanently reside or live in the environment of these lines, we assume it to be 5 kV/m, and compared with the measurement results, all measurement values are within the permissible values.

Using the measured values of the electric and magnetic field strengths generated in the environment of high-voltage overhead power lines, based on electromagnetic field theory, which calculates the electric and magnetic field strengths generated at a certain distance from the line wires, their geometric parameters, we derive a formula for calculating the strength of the electromagnetic field, perform the calculations, and create the corresponding graphs. When comparing them with the measured values, the shapes are very similar.

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