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# **Preserving Knowledge in Power Line Engineering with Language Models and Design**

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and Management**

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**Preserving Knowledge in Power Line  
Engineering with Language Models and Design**

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# Abstract

The loss of senior expertise in power line design poses a critical challenge to the sustainable energy transition. Current methods of knowledge transfer fail to prevent the loss of invaluable knowledge necessary for future junior power line designers. Additionally, the rise of informal deployment of generative language models may also threaten to bury hand-written knowledge documents before this knowledge can be extracted, structured, and preserved for future guidance.

This thesis proposes a framework where large language models are integrated into knowledge transfer and decision-making guidance for an engineering enterprise. Using this framework, this thesis further explores how data-driven knowledge tools can assist junior design engineers by supporting information retrieval and directing to knowledge sources. The ability of a large language model to retrieve relevant knowledge from an engineering design document was validated by comparing the process of human designers manually completing a similar task. In this evaluation involving six participants and the large language model, responses to questions on mechanical dimensioning of stays for utility poles were ranked by experts. The results showed that the large language model responses were ranked similarly to the junior designers on average. Additionally, a small-scale demonstrative knowledge tool, insights from interviews, literature studies as well as the results from the validation study lead to the conclusion that large language models can assist power line designers via a knowledge tool. Beyond power line design, this thesis contributes to the understanding of how data-driven language models can assist knowledge retrieval and decision-making across other engineering design domains. This work utilizes a professional education document on the mechanical dimensioning of wooden power line poles including an analysis on the wind and weight span's affect on the dimension of the pole, developed parallel to this work. The original design data from the document supported the tests conducted in this thesis. The professional education document on the mechanical dimensioning of wooden power line poles was developed in parallel to this thesis as a case study supporting the tests with original design data on power line design knowledge.

The work also discusses risks and ethical aspects when implementing such a knowledge tool. Risks such as leakage of classified information are emphasized and need comprehensive systems and methods to be avoided. It is therefore highlighted how important it is to carry out the project with care and expertise to avoid damage to companies and society. Local language models or highly trusted AI system providers are recommended to ensure that no sensitive information is leaked to an unwanted third-party. With a high degree of caution and consideration of risks, an effective knowledge tool can contribute to increased efficiency, faster and more sustainable development of power line infrastructure, and thus an faster energy transition.

**Keywords:** Knowledge Preservation, Power Line Design, Design Representation, Engineering Design, Mechanical Dimensioning, Large Language Models, Artificial Intelligence

## Sammanfattning

Förlusten av senior expertis inom kraftledningskonstruktion utgör en kritisk utmaning för den hållbara energiomställningen. Nuvarande metoder för kunskapsöverföring är otillräcklig för att förhindra förlusten av ovärderlig kunskap som är nödvändig för framtida juniora kraftledningsprojektörer. Dessutom kan den ökade informella användningen av generativa språkmodeller hota att begrava mänskligt skrivna kunskapsdokument.

Detta arbete presenterar ett ramverk där storskaliga språkmodeller används för att underlätta kunskapsöverföring och tillhandahålla vägledning vid beslutsfattande inom ingenjörsföretag. Med hjälp av detta ramverk utforskar arbetet ytterligare hur datadrivna kunskapsverktyg kan hjälpa juniora kraftledningskonstruktörer genom att stödja informationsinhämtning med hänvisning till kunskapskällorna. En storskalig språkmodellens förmåga att hämta relevant kunskap från ett tekniskt designdokument validerades genom att jämföra processen för mänskliga designers som manuellt slutförde en liknande uppgift. I denna utvärdering, som involverade sex deltagare och den storskaliga språkmodellen, rankades svaren på frågor om mekanisk dimensionering av stag för kraftledningsstolpar av experter. Resultaten visade att den storskaliga språkmodellens svar i genomsnitt rankades på liknade nivå som de juniora ingenjörerna. Tillsammans med ett småskaligt demonstrativt kunskapsverktyg, insikter från intervjuer med kraftledningskonstruktörer, litteraturstudier samt resultat från valideringsstudien dras slutsatsen att storskaliga språkmodeller kan stödja kraftledningskonstruktörer via ett kunskapsverktyg. Utöver kraftledningskonstruktion bidrar detta arbete till förståelsen av hur datadrivna språkmodeller kan hjälpa till med kunskapsinhämtning och beslutsfattande inom andra tekniska designområden. Arbetet använder ett professionellt utbildningsunderlag om mekanisk dimensionering av kraftledningsstolpar i träkonstruktion, inklusive en analys av vertikala- och horisontella linspannets påverkan på stolpens dimension, utvecklat parallellt med detta arbete. Originaldesigndata från underlaget stödde de tester som genomfördes.

Arbetet belyser även risker och etiska aspekter vid implementering av ett sådant kunskapsverktyg. Risker som läckage av sekretessbelagd information betonas, och omfattande system och metoder behövs för att undvika dem. Därför understryks hur viktigt det är att genomföra liknande projekt med noggrannhet, försiktighet och expertis för att undvika skador på företag och samhälle. Lokala språkmodeller eller API-leverantörer med högt förtroende rekommenderas för att minimera risken att känslig information läcker ut till en oönskad tredje part. Med stor försiktighet och hänsyn till riskerna kan ett effektivt kunskapsverktyg bidra till ökad effektivitet, snabbare och mer hållbar utveckling av kraftledningsinfrastruktur, och därmed en snabbare energiomställning.

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## Nomenclature

AI: Artificial Intelligence  
API: Application Programming Interface  
CIO: Chief Information Officer  
EBR: ElnätsBranchens Riktlinjer  
GPT: Generative Pre-trained Transformer  
LLM: Large Language Model  
MMLU: Massive Multitask Language Understanding  
NLP: Natural Language Processing  
SDG: Sustainable Development Goals  
SEK: Svensk Elstandard  
SQuAD: Stanford Question Answering Dataset  
STEM: Science, Technology, Engineering, and Mathematics  
UM: Uppdragsmodellen

# 1 Introduction

Mitigating climate change requires a build out of clean energy production, which then also requires more development of the power line infrastructure [1]. This increasing demand results in an increased workforce demand for engineers with knowledge in power line design [2]. Most of the transmission supports in Sweden in use today was built decades ago due to a growing electricity production which especially came from nuclear power [3]. From around 1990 to 2010, see Figure 1, the trend for electricity production in Sweden stagnated which led to a decrease in demand for new power line infrastructure. During this time of slower development, the field of power line design mainly focused on maintenance of current infrastructure, thus leading to a decrease in the demand for power line designer workforce during that period. But looking ahead, the power line infrastructure is expected to require significantly more development to support the expected increase in electricity production. With a limited number of senior engineers and a high growing number of novice engineers rolling into the workforce, a challenging unbalance in knowledge has appeared. Many of these senior engineers possess a lot of experience and knowledge about the decision making process for designing power line supports, while the novice engineers rely heavily on supervision from the seniors.

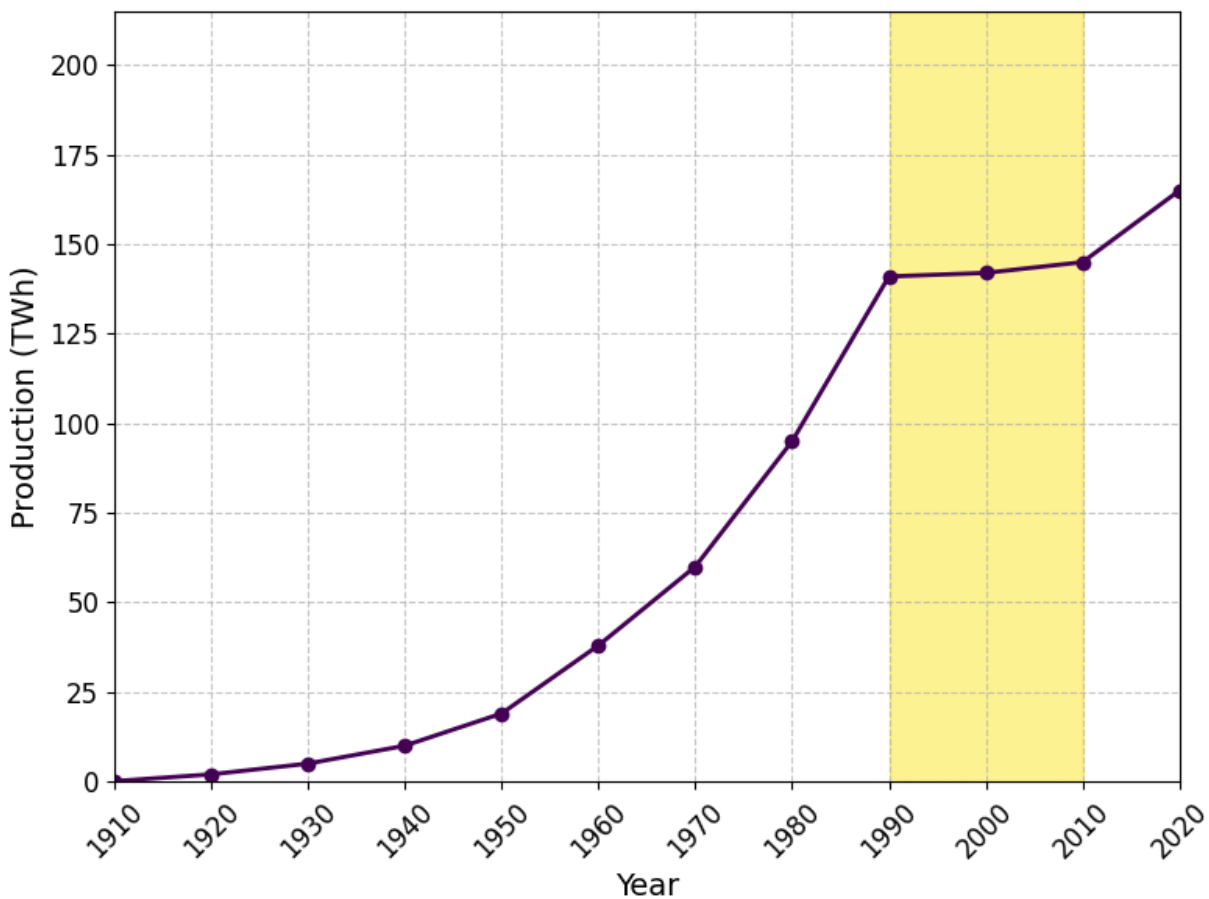


Figure 1: Sweden's electricity production by decade from 1910 to 2020 with expectations of further increase in development in the nearest decades [4] [5]. From around 1990 to 2010 resulted in a more stagnant development of electricity production.

The stages for developing expertise in engineering design can be broken down and described into four stages [6]. These stages are generally describing how novice design engineers develop from working with a rule/convention-based way of design thinking to a more situation-based/strategy-based type, and finally to working more with innovation. This development is illustrated in Figure 2 below.

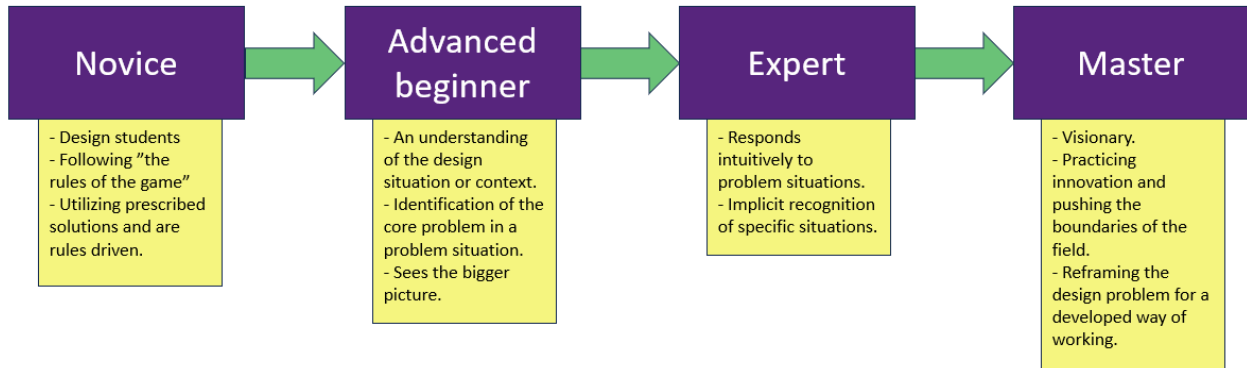


Figure 2: Development progress from novice to master design engineer.

Excessive work for transferring this knowledge has been made in the form of standardising norms, distributing educational handbooks and creating internal instructional documents within power line design organisations. But the speed of which the senior engineers go into retirement versus the speed of increasing novice engineers make the knowledge transfer insufficient for making sure loss of invaluable knowledge is prevented [2]. Figure 3 shows how current engineering design knowledge transfer is made, and how AI could improve the transfer process.

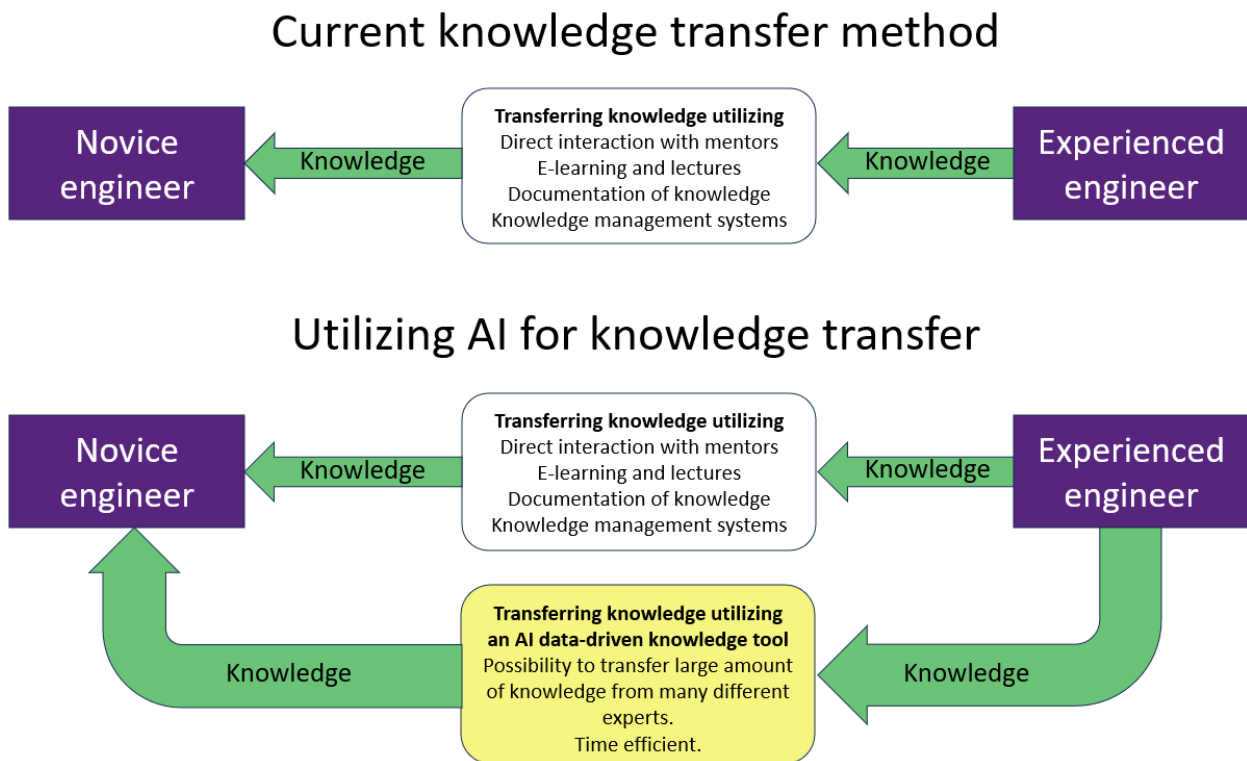


Figure 3: Overview the knowledge transfer from experienced to novice engineer designers usually is made and how it could be different utilizing AI.

This thesis explores new methods for capturing and transferring this knowledge using generative artificial intelligence. Such technology has shown potential for tasks such as identifying functional requirements and design parameters in previous works [7]. If the senior power line designer knowledge could be captured and transferred to the novice engineers efficiently using an AI-driven knowledge tool, the knowledge gap might

be reduced and the strive for mitigating climate change made easier.

Nordisk Elkraftteknik AB (Nordic electric technology AB) NEKTAB is a Swedish consulting company in the energy business which specializes in power line design and among several other energy and sustainability services [8]. The company provides planning of sustainable power line infrastructure at voltage levels from 10 to 400kV, and are therefore involved in both the local, regional and transmission grid development. Since its birth in 2007, NEKTAB has put a high focus on cooperation with partners within the energy business. In 2020, the company reached top 5 of the companies delivering to the largest electricity companies in Sweden: Ellevio, Svenska kraftnät and Vattenfall Eldistribution. And in 2023, NEKTAB cooperates with more than 250 sub-consultants. As demand for clean energy solutions grow, consulting companies like NEKTAB play a crucial role in expanding the necessary power line infrastructure. This thesis performs a case study at NEKTAB for exploring how an AI-driven tool could help reduce the knowledge gap in power line design.

This thesis is organized into 9 chapters. Chapter 2 describes the problem addressed in this work. Chapter 3 states the objective and research question. Chapter 4 provides a comprehensive background and literature study. Chapter 5 describes the methodology involving the development of an instructional document and mechanical analysis for power line design, development of a demonstrative proof-of-concept AI-driven knowledge tool and a test study with an LLM. Chapter 6 presents the results from the conducted steps in the methodology. Chapter 7 discusses the key insights and risks of this kind of technology. Chapter 8 presents the concluding remarks and future work. Lastly, chapter 9 shows the appendix with the interviews, documents and input data for this work.

## 2 Problem statement

As the energy sector undergoes a rapid transition, the demand for experienced power line designers is increasing. However, a significant portion of critical design knowledge rests with senior engineers nearing retirement. Inadequate knowledge preservation within the power line design industry, along with a rapid informal adoption of generative language model tools, can lead to inefficiencies and loss of expertise when these expert seniors retire, illustrated in Figure 4. The potential consequences of this problem are design errors, project delays, increased costs and loss of valuable experiences and insights. Project delays in this field can lead to hurdles when undergoing a clean energy transition, thus slowing down the mitigating of climate change.

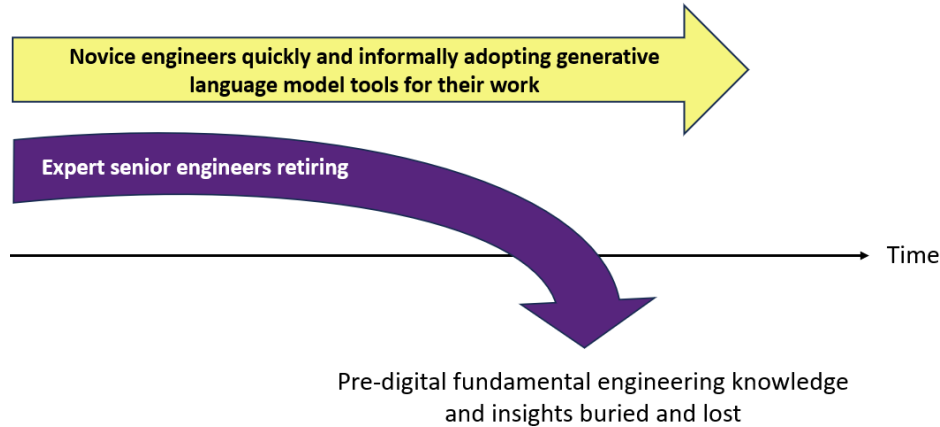


Figure 4: Illustration of how senior engineer pre-digital knowledge and insights risks getting lost forever if not preserved and transferred to emerging engineers.

One area where the knowledge gap is highly present is in mechanical design of the power line poles [2]. Creating an original document describing this process naturally complements the investigation of how an AI-driven knowledge tool could comprehend design information, making sure the LLM did not use the information during its training due to the document being originally made. Therefore, developing an educational document on the process for calculating the minimum required pole class for wooden utility poles, including an analysis how the wind span and weight span affect the dimensioning stage is conducted parallel to the investigation of utilizing an AI knowledge tool. The educational document together with additional collected data will be utilized for exploring how an AI-driven knowledge tool could comprehend and transfer the knowledge to junior engineers.

## 3 Objective

The research objective of this thesis is to explore and evaluate if an AI-driven knowledge system effectively can transfer mechanical power line design knowledge to novice engineers. In order for such a system to work satisfactory, it must be able to comprehend the complex engineering design knowledge in the documents. Therefore, a test-study is conducted to assess the effectiveness of a state-of-the-art AI model in knowledge representation for storage and retrieval with access to a short text about mechanical design for power line poles, by comparing the ranking of its responses against those from junior engineers, evaluated by expert designers. Additionally, this research aims to develop a framework that will guide the future exploration of an AI-driven knowledge system.

### 3.1 Research question

Can the potential loss of power line design knowledge and expertise from retiring senior engineers be mitigated?

## 4 Background

Engineering design can often seem complex to many novice engineers when emerging into their new career. This section presents the literature study on artificial intelligence and power line design.

### 4.1 Artificial intelligence and the emergence of large language models

Key advances in AI research accelerated in the 1950s [9]. The knowledge-based approach in AI began in the middle of the 1960s. A project to implement an expert system named DENDRAL was conducted at Stanford University. Expert systems were designed to mimic the decision-making ability of human experts in specific domains [10]. These systems were part of a broader field of artificial intelligence and were designed using a formalized set of rules and are sometimes called rule-based systems. Deep learning [11] was introduced as the concept of using computational models to process multiple layers to learn representations of data with multiple layers of abstraction.

In 2017, an attention based mechanism for neural networks named Transformer was presented. Without the Transformer architecture, deep neural network gradients used for learning becomes progressively smaller when back-propagated through the layers. Figure 5 demonstrates how previous recurrent neural network lacked longer contextual understanding and how the attention mechanism made it possible. Unlike older architectures, transformers rely on a mechanism called self-attention to decouple distance between words in a sequence by learning semantic relationships, solving the so called vanishing gradient problem. Transformers revolutionized language modeling by allowing them to process input sequences in parallel and understanding long-range dependencies within text using the attention mechanism. Many of the state-of-the-art language models today are based on the transformer architecture, such as for example OpenAI's GPT-4 and Google's Gemini [12], [13], [14].

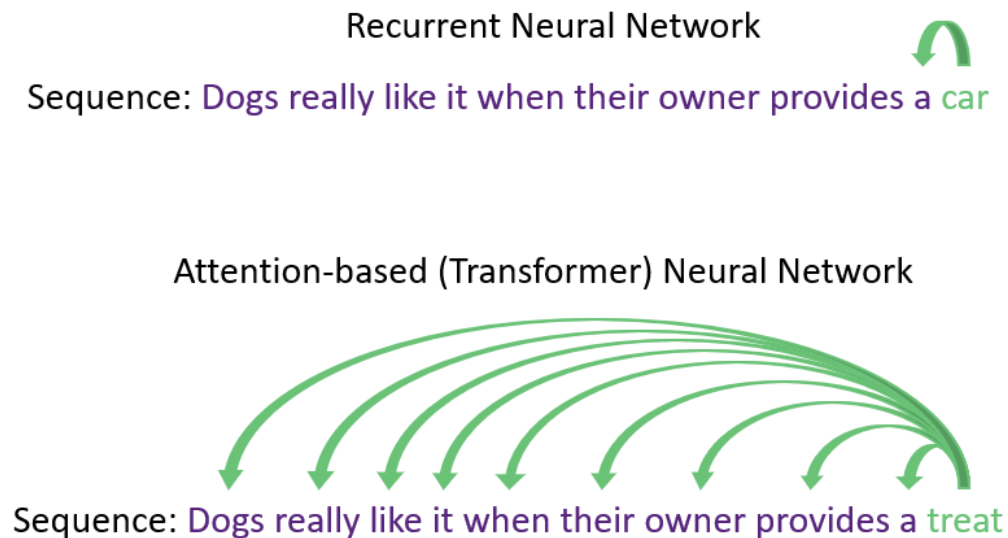


Figure 5: How recurrent neural networks lacked the ability for longer context understanding and how attention based transformer methods solves that.

According to Our World in Data [15], AI systems already perform better than the average human in tasks such as language and image recognition, reading comprehension, speech recognition, language understanding and handwriting recognition [15]. The last decades have seen a rapid exponential increase in the computation used to train these AI systems, and as the training computation has increased, large language models have become more and more powerful on the Massive Multitask Language Understanding (MMLU) benchmark as seen in Figure 6. Investment in this sector is increasing substantially every year [15]. Thousands of AI researchers were interviewed regarding the future of AI [16] where the estimations on if science continues undisrupted, that there was a 10% chance that unaided machines would outperform humans in every possible task by 2027, and 50% by 2047.

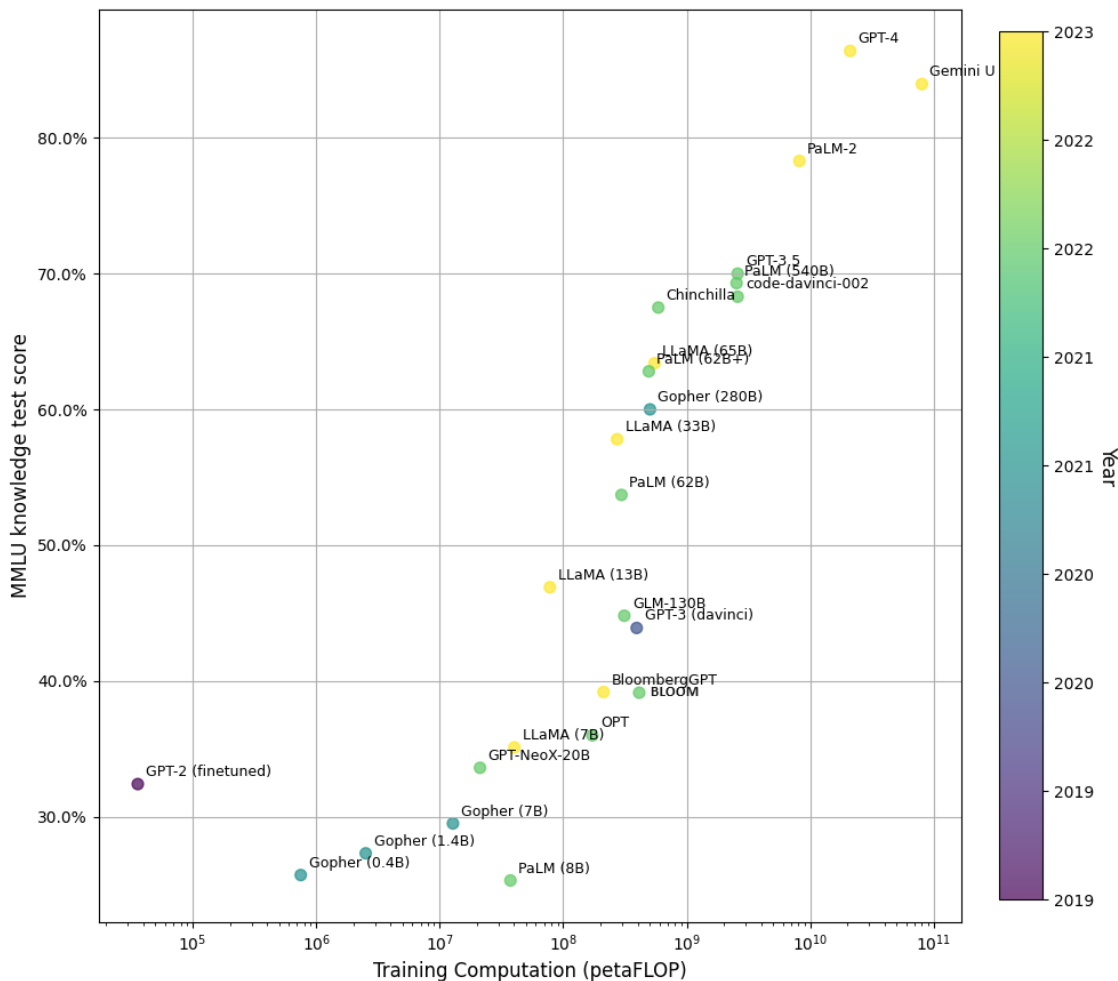


Figure 6: AI performance on the MMLU knowledge test vs. training computation and year of release. [15].

#### 4.1.1 Previous work on evaluating natural language processing systems

Information-theoretic ideas were developed during the 1920s, representing the mathematical quantification, storage and communication of information. In 1948, information theory was established as a discipline and brought immediate world wide attention [17]. In that study, entropy was introduced as a concept measuring the uncertainty and randomness in a dataset, fundamentally revolutionizing the approach to information storage and compression. Practical aspects of information retrieval from large datasets and the internet by using methods like vector space indexing was developed in the 1970s [18], [19].



Decades later, semantic representations of text, functional requirements and design parameters was extracted from complex engineering design information was conducted using the LLM Bidirectional Encoder Representations from Transformers BERT [20]. The studies showed that the LLM successfully extracted the relevant knowledge, thus highlighting discussions about developing knowledge assisting tools for design engineers and the potential positive outcomes [21].

Reading comprehension requires both knowledge about the world and understanding of natural language. Large datasets have played a critical role historically for driving for example object recognition and syntactic parsing in machines forward. To compare a large language model’s ability to understand text, certain evaluation methods and benchmarks have been established. Precision and recall was introduced in the 1950s which measures the effectiveness of information retrieval systems and have been critical for evaluation of performance [22]. Another particularly comprehensive dataset for question benchmarking is the Stanford Question Answering Dataset (SQuAD) [23]. In that paper, a benchmark method for evaluating a machine’s ability to comprehend text was presented. The authors highlighted that datasets needed for training require both size and high quality for making the machines able to perform well.

## 4.2 Artificial intelligence for sustainability

Climate change is urgent, and artificial intelligence (AI) shows potential for enhancing sustainable energy efforts. Preservation and increasing the accessibility of knowledge from experienced engineers to novice engineers is critical for advancing a sustainable development for power line design. As highlighted by interviews with industry actors [5], a critical challenge identified in the sector is the shortage of skilled labor, practically in the production and establishment of power lines. This issue acts as a bottleneck, hindering the energy transition crucial for climate mitigation efforts. Over the past few years, AI has demonstrated remarkable capabilities supporting engineers through complex and precise prediction models, particularly in sustainable energy research and power line engineering [24]. More recently, breakthroughs in Natural Language Processing (NLP) have further expanded the potential to assist through its semantic and reasoning capabilities. The role of AI in supporting the United Nations Sustainability Goals (SDGs) should not be overstated (United Nations, 2023). A comprehensive study by [25] explored the potential positives and trade-offs of AI systems such as ChatGPT and similar systems, on achieving the SDGs. The findings indicated significant potential benefits across several goals. However, training and deploying AI generates CO<sub>2</sub> emissions, as stated in the paper [26]. The study introduced an evaluation method for estimating the carbon footprint emissions associated with AI projects with the goal of reducing emissions in specific projects. Their work revealed that, when used on a small-scale, the negative impacts sometimes resulted in higher emissions compared to the positive impacts. But when scaling up the project with more users, the positive gains reached higher levels compared to the negative impacts. The study underscores the importance of conducting impact assessments on AI systems to reduce the potential trade-offs on the SDGs.

### 4.3 Expert systems for engineering knowledge in power systems

Combining the knowledge from experts with artificial intelligence in the power line industry has already been done under the name Expert systems (ES) [27]. Such systems obtains the knowledge of a human expert in a narrow specified domain and implements it into a computer program. The knowledge is stored in rules, decision trees, models and frames, thus sometimes also called rule based systems. ES have been widely used in automation in other fields than power systems.

As seen in Figure 7, ES mainly consists of a knowledge base, inference engine user interface and a knowledge acquisition system. The knowledge base consists of expert knowledge and database knowledge [27]. The inference engine is a rule-based processing component that derives conclusions from the knowledge base and the user interface is where the user interacts with the ES. The knowledge acquisition system is the system where the expert interacts with the ES to create, add or change the knowledge base, which has been deemed as a time consuming process. The knowledge capturing from the experts is often the bottleneck when creating these systems [28].

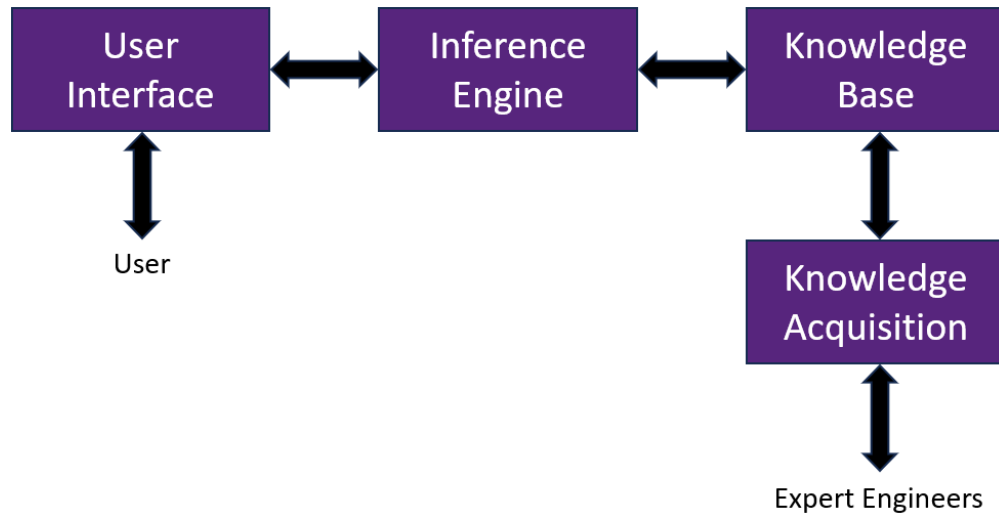


Figure 7: Overview of the process for Expert systems.

The main advantages for these systems that relates to the work in this thesis are that they can increase productivity, reducing training for employees and give answers for repetitive decisions, processes and tasks. The main disadvantages for these systems are that they lack human common sense, lack flexibility to adapt to changing environments, limited reasoning under the rules it was given, very expensive to set up initially and risks of potential errors [28].

#### 4.4 Power line design

Power line infrastructure in Sweden began appearing late in the 19th century. Initial wooden power lines poles had different structures than modern ones, see Figure 8 showing a power line pole during the 1910s decade in Bäveån Sweden.



Figure 8: Power line structure at Bäveån, Bohuslän, Sweden in the 1910s decade supporting transmitting power from hydro power plants for distribution [29].

Much of the infrastructure in use today was built many decades ago and is approaching its end of service date [3]. The power line infrastructure is now undergoing a substantial build out and refinement. The steel- and iron industry are electrifying their processes to reduce their carbon footprint, chemical industries are further developed, heat pumps are implemented more frequently, new energy intensive server halls and battery factories lead to high demands on an already limited power line infrastructure [1]. See Figure 9 for a typical power line in use today in Sweden.



Figure 9: Regional grid power line over Flatruet in Härjedalen Sweden [30].

The first Swedish regulation for mechanical dimensioning of power lines was formed in 1912 [31]. Power line poles in previous projects had been dimensioned according to specific rules, but with the regulation came a uniform standard. Several regulations were formed since then and today the poles have to meet the minimum requirements set in the “Swedish Standard” by Svensk Elstandard [32].

#### 4.4.1 Knowledge gap between novice and seasoned engineers

The disparity in expertise between novice and seasoned power line design engineers is significant [2] while additionally the scarcity of skilled labor in the field is high [5].

There are many factors that affect the design of power line systems. Some of these are for example distances between the power line pole structures, line loads such as wind- and ice, line area, line drag forces and potential unwanted insulator angle change and much more [33]. Therefore, the complexity of designing these structures requires significant knowledge and in many cases insights from previous project experiences.

Workforce shifts leads to large gaps where new engineers have to spend a high amount of time figuring out how some systems work or behave.

### 4.5 Mechanical dimensioning of wooden power line poles

Mechanical design of power line pole structures is essential for the poles to withstand the many different loads during its operational life time. Permanent loads mainly come from the insulators, poles own weight, conductors and top lines. Variable loads come from the wind on the lines and pole, ice and maintenance work on the pole [34]. These loads result in the forces seen in the figure 10 that illustrates a typical tangential pole with stays.  $K_F$  represents the resulting buckling force,  $H_{F_{vtopp}}$  for the horizontal force from the top lines,  $H_{F_v}$  for the horizontal force from the conductors,  $H_{F_s}$  for the horizontal force from the wind on the pole, and  $M_J$  for the resulting momentum at the ground level from the horizontal forces.

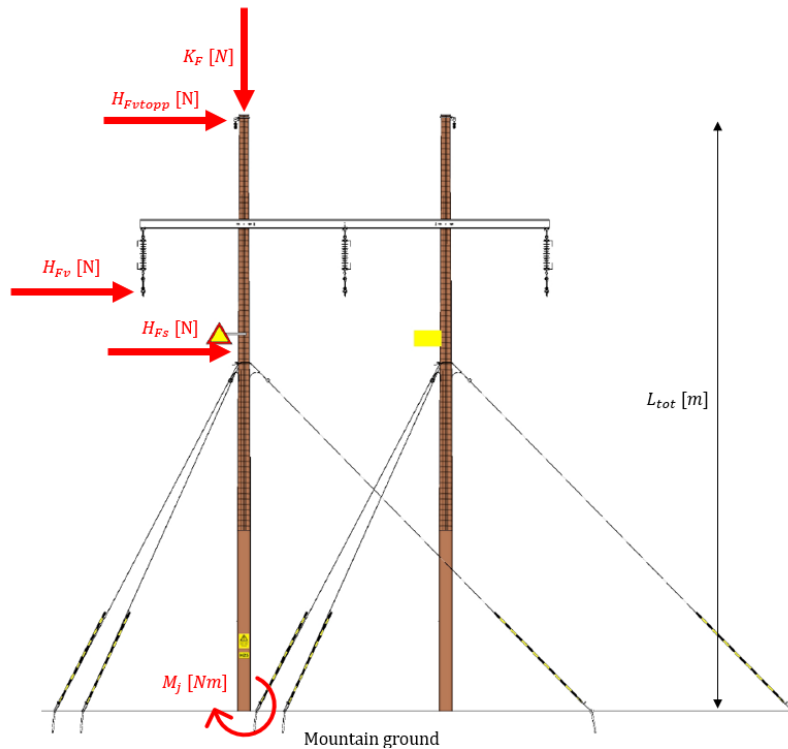


Figure 10: Illustration of a tangential power line pole with its resulting buckling forces, horizontal forces and resulting momentum at the ground level. Credits to Jarl Bergström who contributed with the figure of the pole structure. Illustration of the forces was made by the author of this work.

Open literature on the calculation process for dimensioning of power line poles can be found in a few previous works [3], [33], [34], [35]. These reports presents a thorough work for describing calculation methods and different analyses for the design and placement of the poles, thereby fueling this work with a lot of knowledge to build on. The functional requirements for the dimensioning of the wooden power line poles mainly comes from the standardised norms decided by Svensk Elstandard SEK [32]. SEK is an organisation where around 800 experts from different Swedish companies, government organisations and universities decide on the standards for power systems. International cooperation is often conducted during the standardisation process.

Lisa Svanholm, a seasoned power line designer at the consulting company NEKTAB highlighted the lack of educational and intuitive literature for helping novice engineers understanding the entire dimensioning process. She highlighted the need for literature with explanations behind the standard formulas and saw the need for descriptions on why and how certain assumptions were made.

Special functional requirements can also be set by the power line owner to address specific geographic conditions, load factors, or other unique needs in their network [36].

Jarl Bergström, another seasoned power line designer at NEKTAB developed and internally launched a program for dimensioning power line poles, with additional calculation possibilities. The code repository for this program and support from Jarl also provided a lot of knowledge for conducting this work.

#### 4.5.1 Wind span and weight span

The lengths of the wind span ( $a_h$ ) and weight span ( $a_v$ ) highly affect the dimension of the power line pole structures. But the method for determining these variables before the dimensioning phase not well-known. The wind- and weight span describe the distance between specific positions for a power line pole's conductor as seen in Figure 11.  $a_h$  is the mean value of the two closest span lengths and is used to calculate horizontal forces.  $a_v$  is the distance between the two closest span lengths vertex and is used to calculate vertical forces [34].

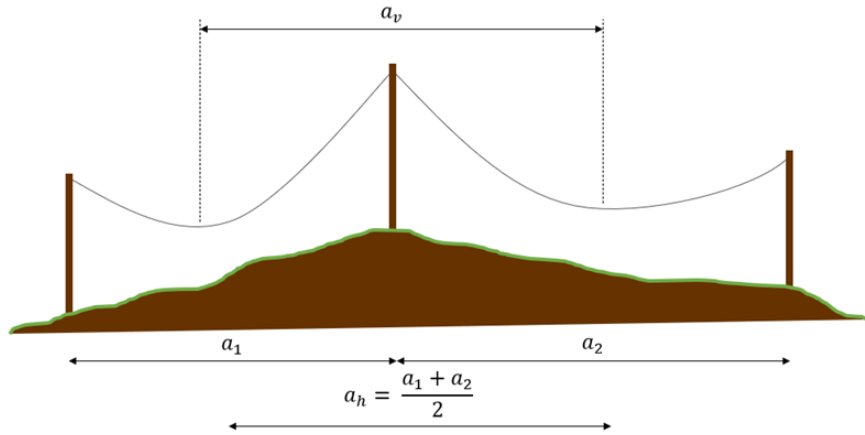


Figure 11: Illustration of the wind- and weight spans ( $a_h$  and  $a_v$ ).

The following equations are generally used to calculate the horizontal and vertical forces on the pole from the power lines [34]:

$$F_{\text{vertical}} = n \cdot a_v (q_e y_{e1} + q_{i0} y_{e2}) [N] \quad (1)$$

$$F_{\text{horizontal}} = n \cdot a_h \cdot Q_{vi} \cdot y_{e2} [N] \quad (2)$$

Where:

Description	Symbol	Unit
Number of lines	$n$	–
Safety factors determined by the norms	$y_{e1}, y_{e2}$	–
Load from the line weight	$q_e$	$N/m$
Load from line covered with ice	$q_{i0}$	$N/m$
Load from wind and ice	$Q_{vi}$	$N/m$

Table 1: Description of variables and constants for equations 1 and 2.

Therefore, the  $a_h$  and  $a_v$  highly affect some of the main forces determining how thick the diameter of the pole must be to withstand the bending and buckling stress. The placement of power line pole structures is usually made during the so-called profile design with Computer Aided Design (CAD) software. As seen in Figure 12 below, this process is usually conducted before dimensioning the power line pole structures, despite that the dimensioning itself being highly affected by the distances between the poles. This leads to the profile design phase many times being remade or refined due to the dimensioning requirements being unfulfilled, thus extending the project time and costs [2].

A previous master thesis student at NEKTAB conducted a thorough work on deriving complex formulas and developing nomograms for  $a_v$  and  $a_h$  [35]. The work concluded that using these nomograms would provide a quick solution for the dimensioning of the poles. The nomograms have been utilized and has contributed to power line design knowledge. The author of this thesis wanted to contribute to his work by conducting an analysis for conductor of size  $910mm^2$  as well, which was not included in any of the nomograms. The conductor size of  $910mm^2$  is commonly used within power line systems [2].

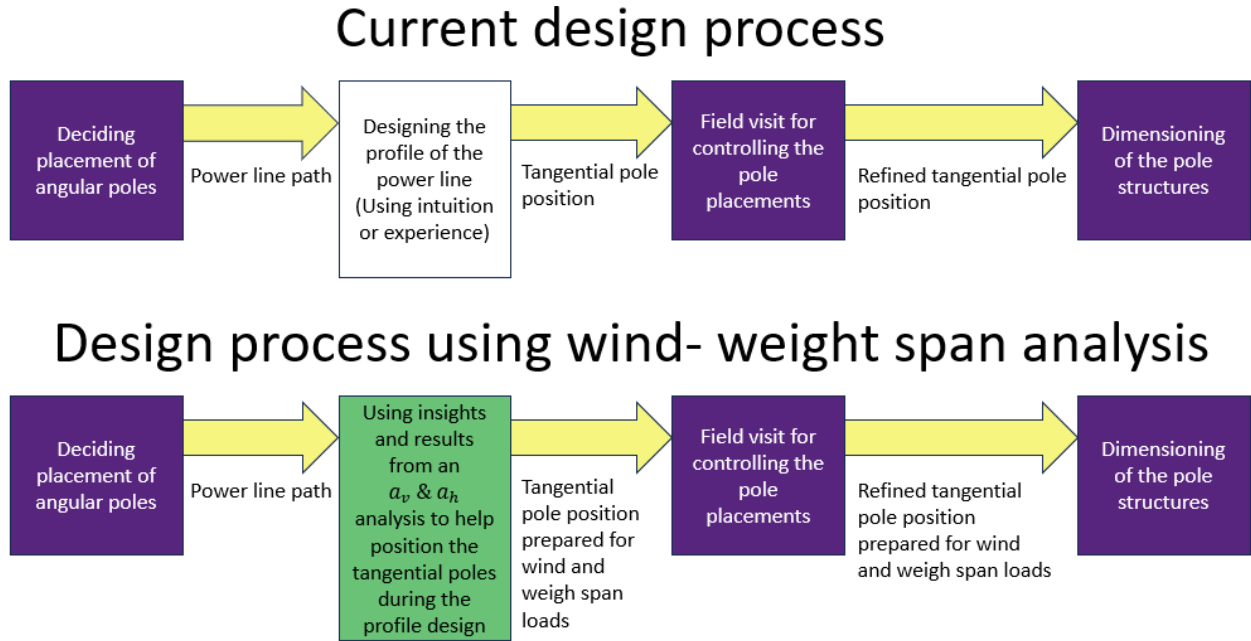


Figure 12: Designing power line poles by incorporating insights or results from the effects of wind and weight span on dimensioning helps mitigate the risk of having to restart process at the tangential pole placement stage.

## 4.6 NEKTAB

NEKTAB is a consulting company that provides planning of sustainable power line infrastructure at voltage ranges from 10 to 400kV. Their vision is to drive the the development of a sustainable society with specialists in power line solutions. Their main approach in achieving this is by offering comprehensive solutions with expert knowledge in developing cost-effective and sustainable electricity grids close cooperation with its clients and partners [8]. Regional power grid planning is one of the nine main areas of expertise within NEKTAB. The voltage for this grid level ranges between 40 to 170kV [8]. This grid level will be the focus within this thesis. Knowledge preservation within power line design is a high interest and focus at NEKTAB. Driven by Lisa Svanholm at NETKAB, a method for exercising this preservation of experiences and creation of instructional manuals has been developed under the name Uppdragsmodellen (UM). This storage of expert knowledge provide guidance for the engineers by allowing a more effective knowledge transfer. NEKTAB is undergoing a rapid expansive phase, but at the time this report was written they had 140 employees, 450 consultants over 18 cities in Sweden.

## 4.7 Interviews

Interviews with engineers and knowledge preservation experts were conducted both within and outside of NEKTAB. Lisa Svanholm, the industry supervisor and knowledge preservation expert at NEKTAB provided guidance and insights into the challenges and limitations in knowledge for power line design. Peter Silverhjärta, another knowledge preservation expert working at the industry collective organisation ElnätsBranchens Riktlinjer (EBR) provided insights about how new AI technology might impact different power line companies in Sweden.

Additionally, six junior mechanical design engineers were interviewed to provide work experience to be able to test a proof-of-concept AI-driven knowledge tool. These interviewees also contributed with their time for a test that gave a better understanding of how well a LLM could comprehend engineering design text. Anonymity for the interviews was established for the integrity of the participants. The interview notes from almost all interviews except from the industry supervisor Lisa Svanholm are presented in the appendix. The insights from the industry supervisor was mainly shared during online video call meetings, therefore there are no interview notes provided for this in the appendix. However, the contact information is provided in the bibliography.

## 5 Methodology

Developing a knowledge tool for power line design is an undiscovered field of study, therefore a new methodology has to be developed for this work.

### 5.1 Literature review methodology

A comprehensive literature review was conducted about historic and recent research on AI and power line design. The literature gathered was from Google Scholar, ScienceDirect, supervisors, NEKTAB’s own internal knowledge base and suggested new papers from following leading scientists and entrepreneurs in AI on social media platforms.

### 5.2 Data collection

Collecting data in a high stakes environment like in the power line infrastructure industry requires great caution and clear communication with responsible stakeholders of the data and data security experts at the company. The data should not contain any classified information and should only consist of NEKTAB made content. Data leakage of those kind of documents could pose serious risks to both NEKTAB’s and Sweden’s security. Therefore, 50 instructional documents relating only to mechanical design calculation processes, written down work experiences with different tools and programs, the instructional document and the interview documents created during this thesis work were collected from NEKTAB’s knowledge base UM.

The process for collection the data for this thesis work is illustrated in Figure 13. First, the relevant data sources were identified in the company knowledge base through discussions with the industry supervisor about their relevance to the project. These documents consisted of engineer interviews, NEKTAB-documented work processes with different applications, instructions for NEKTAB-developed codes, self-developed instructional document and other instructions for various work processes all relating to power line design. The second step involved obtaining regulatory approval from the Chief Information Officer CIO to ensure no classified or sensitive information would be used. The third step consisted of acquiring and extracting the approved data from the knowledge base. Due to the fact that LLMs only processing text, all the files were converted to .txt files in this work. Lastly, the data was prepared by removing unwanted file types in the folders downloaded that could not be converted to a .txt format, ensuring that all the data consisted of .txt files organized in the same folder structure as in the company knowledge base. The instructional document (around 100 pages) made during this work was divided into eight smaller text documents to avoid context overflow for the LLM. Some documents also contained a lot of unnecessary white space which was reduced to avoid context overflow.

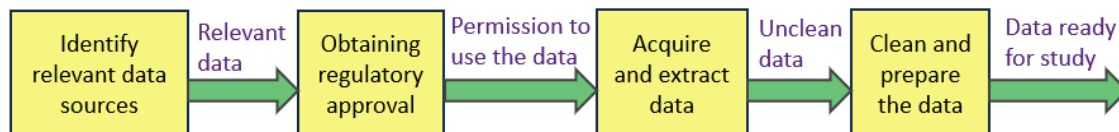


Figure 13: Flow chart illustrating the data collection process for this work.

### 5.3 Proof-of-concept AI-driven knowledge tool

To explore the potential for a small-scale demonstrative AI knowledge tool, different methods were tested using structural representations of the data or communication between multiple LLMs. Embedding models seemed like the easiest and most efficient solution to retrieve the most relevant documents, therefore this work explored applying this technique further. Google Colaboratory, often called Colab, is a free cloud service hosted by Google suited for machine learning, data science and education [37]. Colab provides the ability to use Jupyter Notebook which is commonly used in machine learning. A simple Jupyter code was developed for the knowledge tool. This gave the opportunity to explore if a system using an embedding tool and LLM could effectively retrieve and comprehend relevant power line designer knowledge from a pool of multiple documents. Figure 14 illustrates the documents used for the tool.



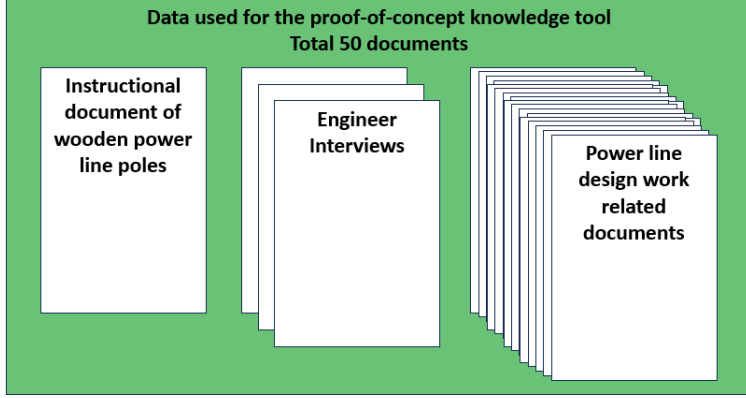


Figure 14: The data used for the knowledge tool study.

Figure 15 shows the main process for collecting the documents and experiences from the interviews, similar to the flow chart for Expert systems shown in the background. The system used Google Drive for storing the documents and allowing a Google Colab Notebook access to the data. In the Colab Notebook, a simple code using Python language was developed. In the code, an embedding model (text-embedding-3-large) was imported from OpenAI API and used to create embedding representations of the words in the documents and the user question. Cosine similarity was used to get the similarity between the user question and the documents using the formula in equation 3. The vectors A and B represent the multi-dimensional data points that together represent the features or attributes from the text.

$$cos_{sim} = \frac{\mathbf{A} \cdot \mathbf{B}}{\|\mathbf{A}\| \|\mathbf{B}\|} \quad (3)$$

The documents were then sorted with the highest cosine similarity values as the most similar document for the user question. To prevent missing important relevant information but at the same time making sure the LLM did not suffer from context overflow, an assumption that the three most similar documents hopefully contained the best information to answer the user question was made. The three most similar documents were then used in the prompt input for the LLM, specifically gpt-4-1106-preview from OpenAI in this work. The LLM's prompt instructions were to analyze the three documents to answer the user question and refer to the document/documents and file path/paths the information was retrieved from. The complete prompt instructions for the model is shown in the appendix.

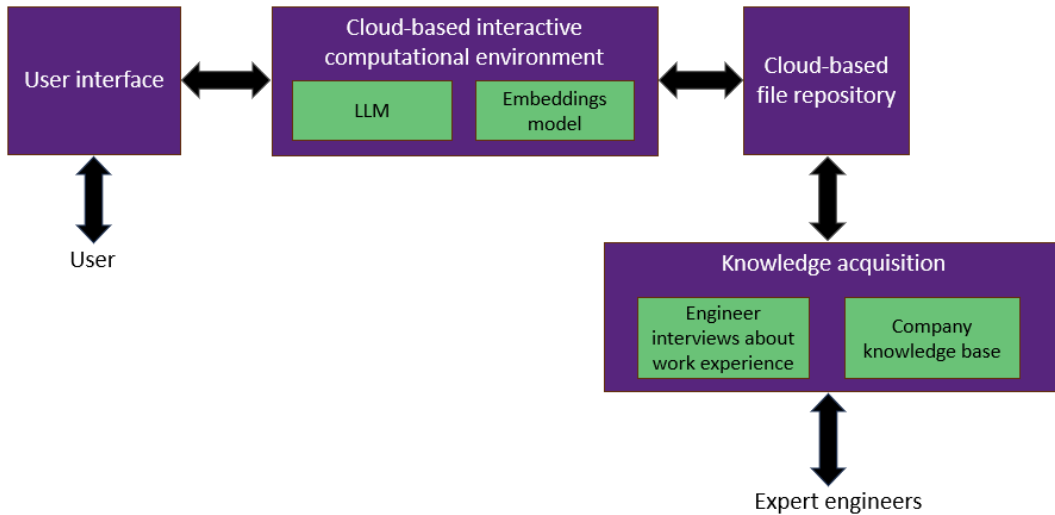


Figure 15: Flow chart illustrating the small scale proof-of-concept AI-driven knowledge tool.

## 5.4 Case study at NEKTAB

The initial scope of the project, as commissioned by NEKTAB due to the knowledge gap in the field, centered around the development of an instructional document and a mechanical analysis. The current open and available papers on mechanical design describe many steps of the design process, but none of the papers describe the whole process in an educational format. Developing such a document describing the derivation and motivations for the calculation steps contributes to mitigating the knowledge gap. However, the risk of not reaching out to the relevant audience for optimizing the knowledge transfer was needed. Therefore, data-driven methods for enhancing the knowledge transfer would be explored for how the knowledge in the document could be retrieved more easily. Therefore the scope of the thesis revolved around utilizing such a tool to help distribute the knowledge from the instructional document and evolved into the idea of an AI driven knowledge tool.

### 5.4.1 Instructional document for dimensioning wooden power line poles

Due to the immense knowledge gap in mechanical design in power line design, an instructional document was made with the purpose to explain a straightforward calculation process. Derivations and explanations of formulas and referencing to where certain safety factors came from were made in an educational format. Illustrative figures and calculation examples were added to help with the understanding for a novice power line design engineer going through the material.

### 5.4.2 Evaluating a state-of-the-art LLM on engineering design text comprehension

For an AI-driven knowledge tool to be useful for power line designer engineers, the technology needs to have a satisfactory comprehension of the knowledge in complex engineering design documents. Therefore, this work focused on testing a state-of-the-art large language model's ability to retrieve the correct information from a chapter in the instructional document created during this thesis. Similar to the SQuAD study, the information needed to answer the test questions was present in the provided document for the participants and the LLM.

Due to the mechanical dimension of stays being one of the more challenging aspects for novice engineers, chapter 3 about stays, seen in Figure 17, was chosen for this research. To simplify the process of getting participants for the study, chapter 3 was shortened down to two pages. Figures were also removed from the document so that the comparison between the participants' answers to the LLM's answers was more scientifically fair. The instructions and text provided to the participants and LLM during the study is shown in the appendix.

<b>Evaluation approach</b>	
Step 1	<p>Formulated the instructions and test questions for the participants. Also prepared the document with the trimmed down information about stays. Removed all the figures to make a fair comparison between the LLM and human participants. The detailed instructions can be seen in the appendix.</p> <p>Five questions with different complexity were provided to the participants during the test:</p> <p><b>Q1.</b> According to the text, name one primary benefit and one primary trade-off of adding stays on a pole.</p> <p><b>Q2.</b> How does the angle <math>\gamma</math> influence the calculated minimum required diameter of the stay?</p> <p><b>Q3.</b> How does the safety factor for the stay influence the minimum required area of the stay?</p> <p><b>Q4.</b> Why is the formula for the vertical force from one stay on the pole different compared to the formula with two stays on a pole?</p> <p><b>Q5.</b> In the text, what method is used to derive the formula that describes the minimum required thickness of the stay?</p>
Step 2	Recruited the junior engineers (6) and experts (2) for the validation phase. Highlighted that the participants answers would remain anonymous.
Step 3	Prepared the documents for the test. One documents with the instructions and questions and another document with the stay information.
Step 4	Conducted the tests with the human participants and ChatGPT-4. ChatGPT-4 received the same instructions except to only look at one question at a time and to notify me when finished with the question due to each question being provided to the LLM one at a time.
Step 5	Gathered all the respondent answers into an Excel-file and shuffled the cells to remove potential distinction between the humans and LLM. Made sure all the answers were anonymous.
Step 6	Expert's conducted the validation were each question was ranked from the worst to the best based on correctness, response satisfaction and helpfulness.
Step 7	Analysed the comparison between LLM and humans with average ranking and made visuals for the results.

Table 2: All the steps carried out in the evaluation performed in this work. More details are presented in the appendix

### 5.4.3 The line loading lengths affect on the dimensioning

An experienced power line designer, Jarl Bergström, at NEKTAB developed a program for dimensioning of wooden power line poles internally at NEKTAB named JBM\_Stolpdimensionering. The work in this study utilized this program for generating thousands of dimensioned power line pole types with different  $a_h$  and  $a_v$  values ranging from 0 to 280 meters. This range was suggested by the industry supervisor as a reasonable span based on work experience [2]. Six different pole structures was compared in this analysis. These pole structures were chosen due to them being common in many projects. Detailed input parameters are presented in the appendix. Table 3 below describes these different pole structures:

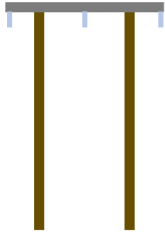
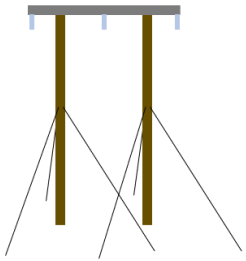
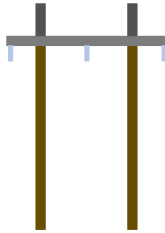
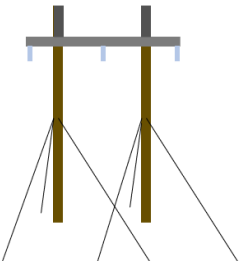
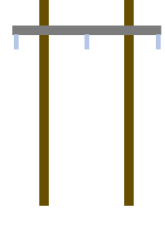
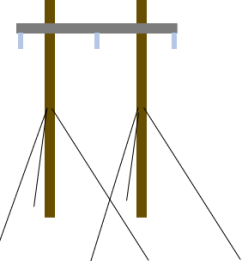
Six pole structures used for the analysis	
Straight line pole with ADSS without 3-stays 	Straight line pole with ADSS 3-stays 
Straight line pole with top line ATLE and steel top without 3-stays 	Straight line pole with top line ATLE and steel top with 3-stays 
Straight line pole with top line ATLE and wood top without 3-stays 	Straight line pole with top line ATLE and wood top with 3-stays 

Table 3: Table of the six pole structures used for the analysis.

A Python script was developed to easily change the relevant inputs for the study, evaluate which poles exceeded the minimum allowed pole type named S+3, which is a commonly used pole class in many projects [2]. Pole classes of higher order can resist higher loads, but might not be available on the market or will increase project costs. The results and lessons learned from the analysis was added to the instructional document for dimensioning of wooden power line poles and later used to test the AI knowledge preservation tool on this knowledge. Due the analysis utilizing the internal program JBM\_Stolpdimensionering, the code for this analysis will not be shared in this report. But to contribute for potential future research about this analysis. The analysis can easily be replicated if given access to a dimensioning program for wooden power line poles. Figure 16 shows the process for the analysis.

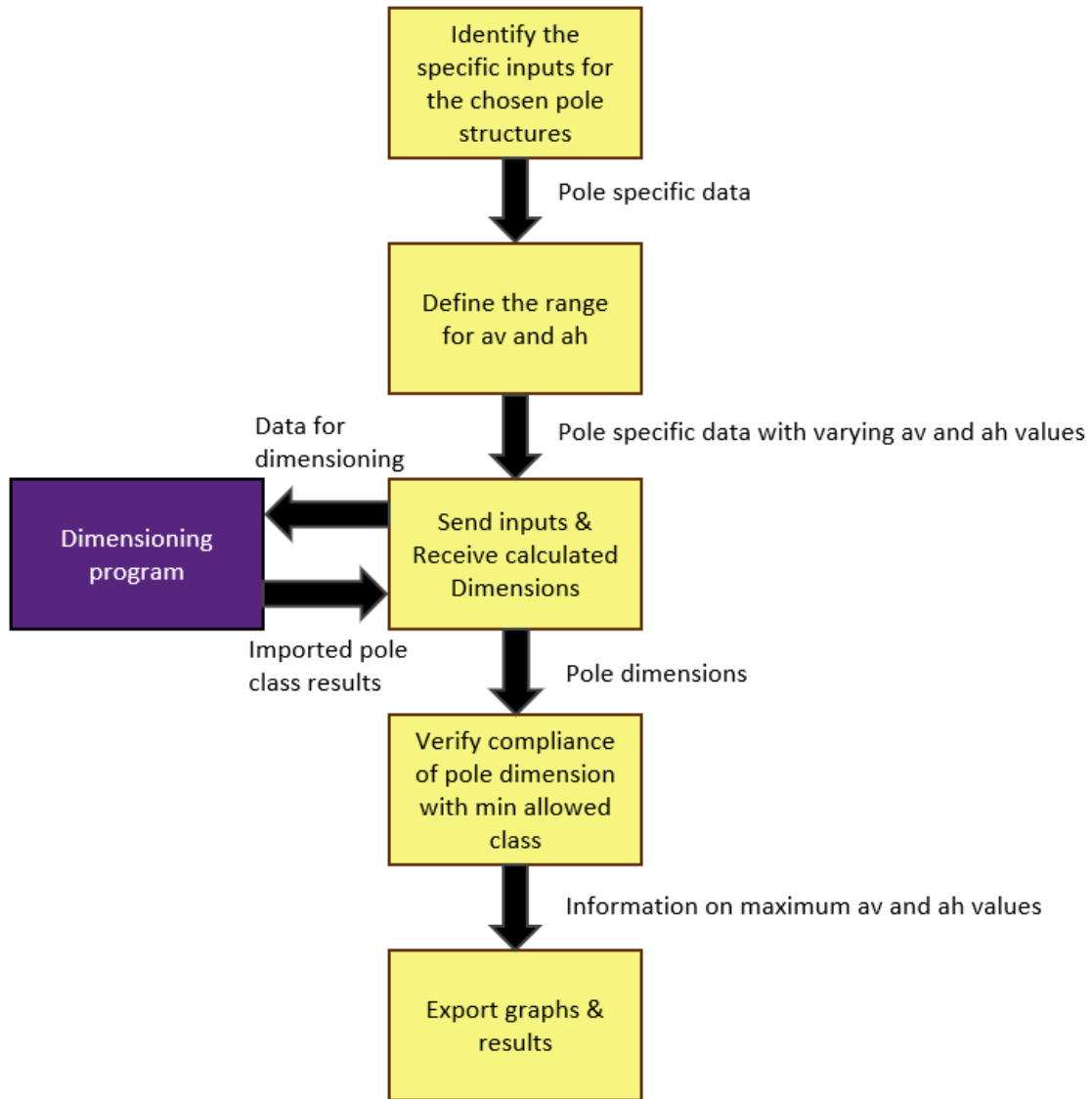


Figure 16: Flow chart of how the  $a_v$  and  $a_h$  analysis can be replicated for potential further research.

## 5.5 Ethical approach in this work

Ethical concerns have risen over the rapid development in generative artificial intelligence. Making sure that the work in this study followed an ethical approach was important. Therefore this study follows ethical frameworks established specifically for generative artificial intelligence [38]. Table 4 lists the main ethical concerns important to consider when conducting projects within generative artificial intelligence.

<b>Main ethical concerns of generative artificial intelligence</b>	
<b>Authenticity and Truthfulness</b>	covers the issues of potential misleading or AI made-up content.
<b>Bias</b>	in generative artificial intelligence occurs from the societal and cultural content in the data which it was trained on.
<b>Transparency and Explain-ability</b>	of how the models can produce its outputs. This covers how the model architecture is built, training data, processes, and understandable reasons for its outputs.
<b>Accountability and Responsibility</b>	raises the questions of who is responsible if the model produces harmful or misleading content.
<b>Intellectual Property</b>	addresses the concerns regarding who would financially benefit from AI generated content and the risks of accidental plagiarism.
<b>Economic and Social Impact</b>	highlights the socio-economic implications regarding potential job displacement and devaluation of human-generated content.
<b>Privacy and Security</b>	address the concerns of potential data leakage and sophisticated cyber-attacks.
<b>Erosion of Human Skills</b>	relates to the reduction in human need when generative AI automates certain job tasks. It also covers the concerns of potential skill loss for humans that over-rely on generative AI for decision making.

Table 4: Description of the main ethical concerns in general artificial intelligence highlighted in the conceptual ethical framework study.

## 6 Results

The following sections present the results from this work. The section is divided into four parts where in the first part, the over-viewing resulting calculation process for the dimensional document is show. Next, the line loading lengths results and take-aways are presented. The third part demonstrates a proof-of-concept knowledge tool's responses. The last part presents the results from the validation study when comparing ChatGPT-4's performance to junior engineers.

### 6.1 Instructional document for wooden power line poles for NEKTAB

An instructional document describing the entire process of dimension power line poles was developed. The main design process that the document described is shown in Figure 17. The experienced NEKTAB engineers Bergström and Svanholm provided with knowledge and feedback that improved the content for the document. Due to data confidentiality and the report containing a lot of knowledge valuable for NEKTAB's intellectual property, only a short section is shown in the appendix.

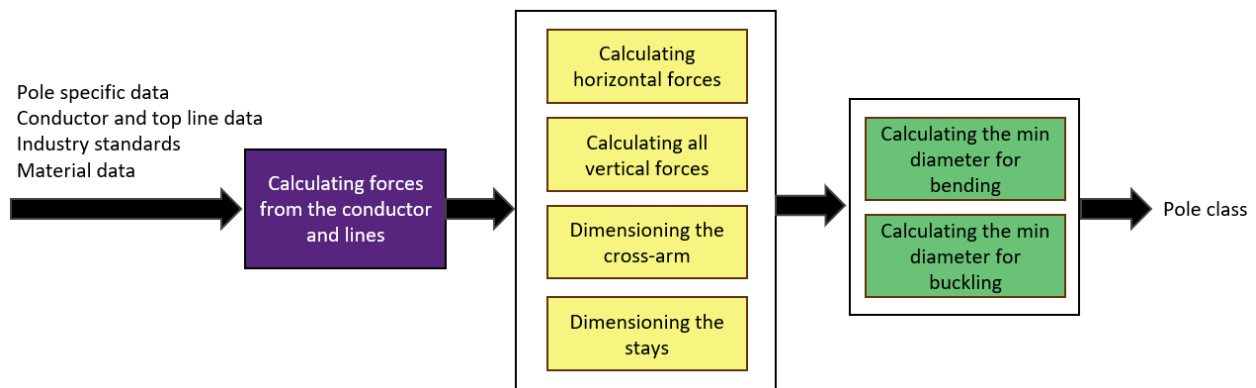


Figure 17: The suggested process for dimensioning wooden power line poles which the instructional document was formed around.

#### 6.1.1 Wind- and weight span analysis results

The results from the line loading lengths analysis were successfully generated using the method presented in this work. An example plot of the generated results for one of the pole structures is shown in Figure 18 below which shows the result of the dimensioned pole classes with its corresponding  $a_v$  and  $a_h$  values. Seen in Figure 18,  $a_v$  values above 140m and  $a_h$  values above 180m required pole classes above S+3 to meet the functional requirements for the pole structure to withstand all the loads. Six similar results were generated to create the final results for all the six pole structures. The final results for the structures without stays are shown in Figure 19 and the ones with stays in 20.

The structures with stays significantly outperforms the structures without stays for allowing higher values of  $a_v$  and  $a_h$  values, even surpassing the suggested maximum  $a_v$  and  $a_h$  values of 280m in some cases. Additionally, wooden top poles seem to allow a higher value for  $a_h$  compared to structures with steel top structures. The pole with ADSS and no stays allows  $a_h$  values of 160m which lies between the maximum  $a_h$  values for the steel and wood top structures, but allowing a higher  $a_v$  at 160m. This is likely due to less vertical load from the the much lighter material in the ADSS line compared to the steel line ATLE and the ADDS pole having a much lighter beam.

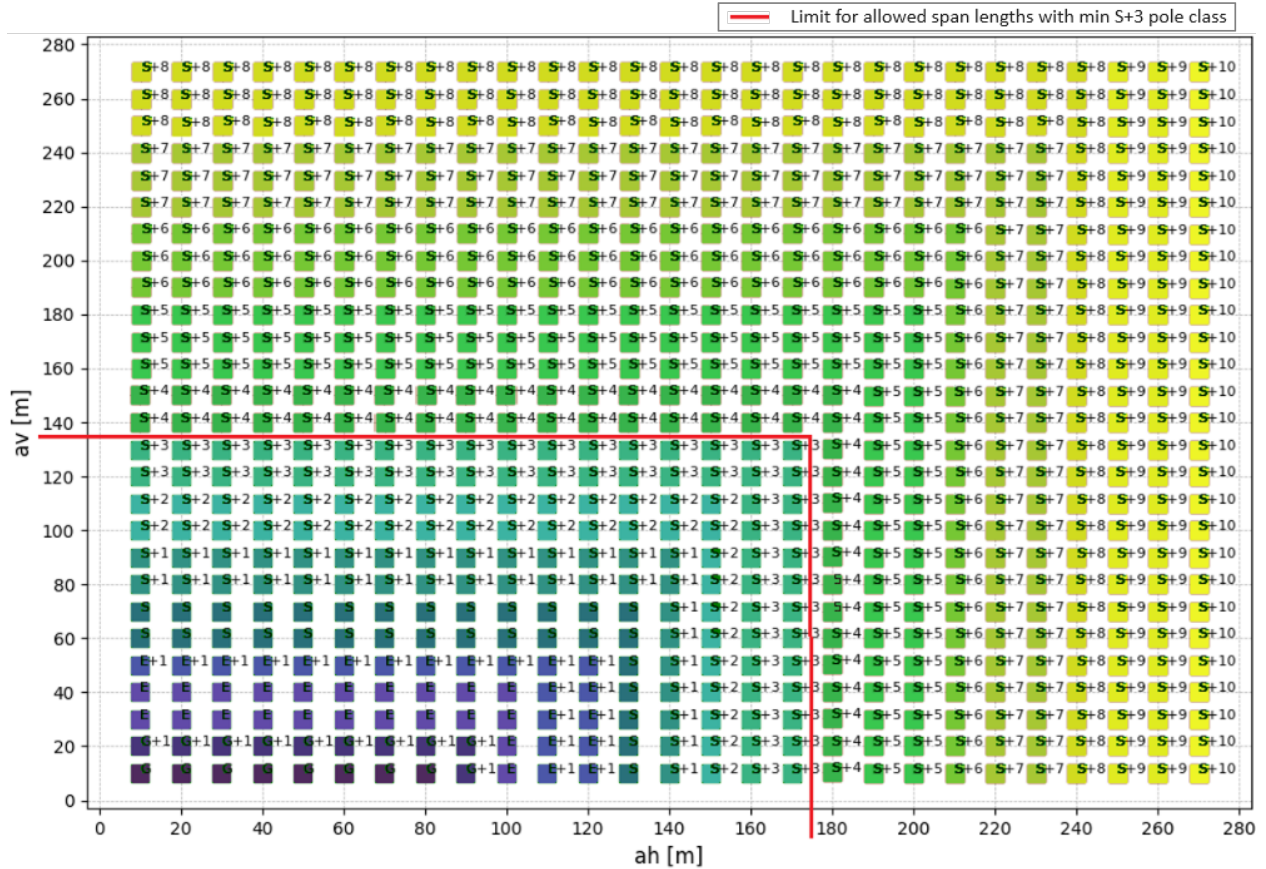


Figure 18: One of six figures showing the generated pole classes with from different combinations for  $a_v$  and  $a_h$  values. The red straight line highlights the limit for allowed span lengths when S+3 is the smallest pole class allowed. The pole structure in this specific figure is the straight line pole with top line ATLE and wood top without 3-stays.



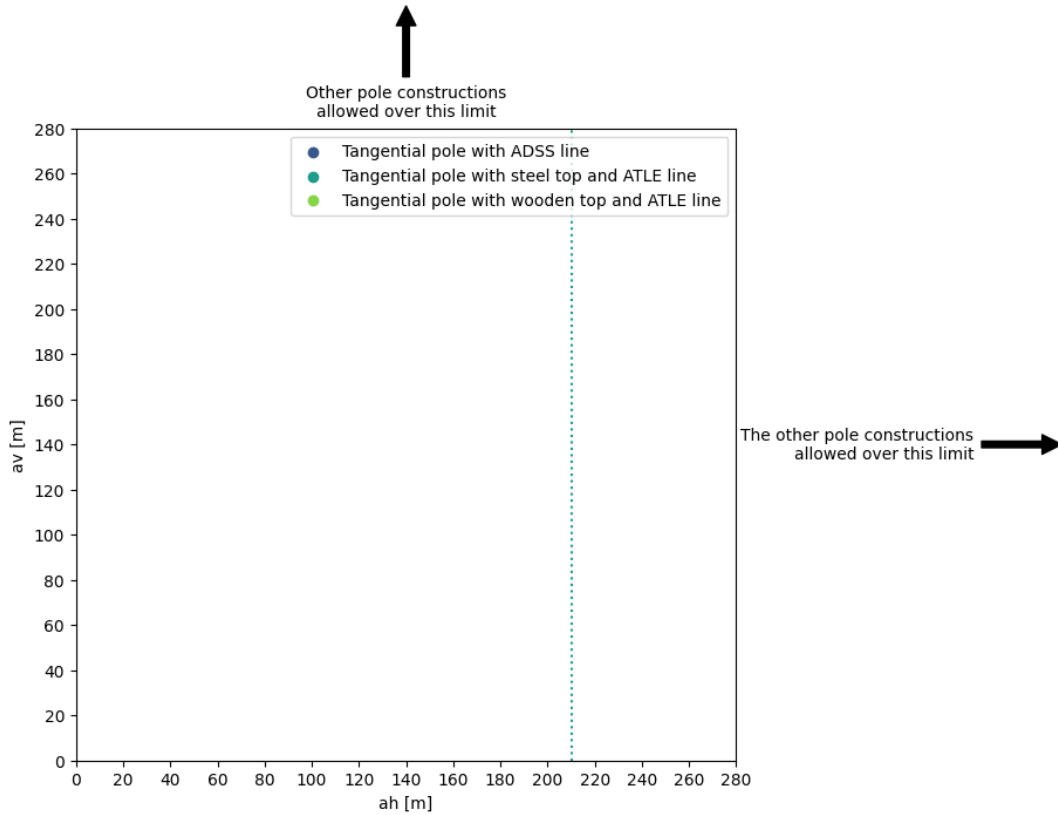


Figure 19: Final results for the max  $a_v$  and  $a_h$  values for a min pole class of S+3 **without** 3-stays.

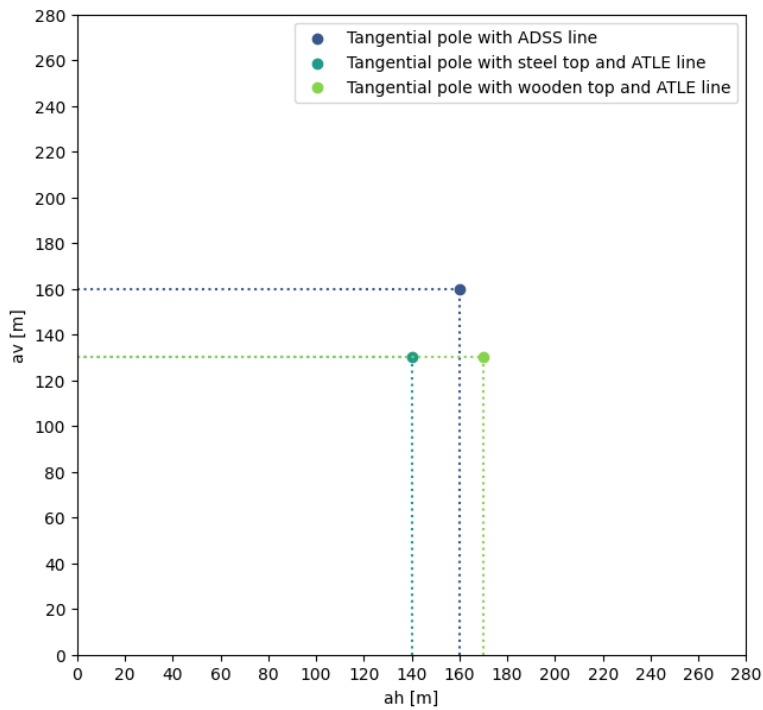


Figure 20: Final results the max  $a_v$  and  $a_h$  values for a min pole class of S+3 **with** 3-stays.

## 6.2 The potential of a small-scale knowledge tool with power line design documents and engineer experiences

The demonstrative knowledge tool developed in this work, utilizing API's from OpenAI, were able to locate relevant complex design information in a pool of 50 documents relating to power line design. Table 5 and 6 shows the (translated from Swedish) input questions and the received outputs from the system which were verified as truthful against the text in the original documents. You can try the code yourself by utilizing an embeddings and LLM API using the following Google Colab notebook:

Code here:

[https://colab.research.google.com/drive/1mDh174iWBo0zqZjJgm0b8Tjp\\_gA3qh0X?usp=sharing](https://colab.research.google.com/drive/1mDh174iWBo0zqZjJgm0b8Tjp_gA3qh0X?usp=sharing)

User Question	Proof-of-concept AI Knowledge Tool Response
I am going to design a line that passes above a railway and under an existing line at the same time. How can I proceed as it seems impossible to meet both height requirements at the same time?	To solve the problem of meeting the height requirements of both the railway and the existing line at the same time, you can consider using a special construction that allows different heights for the conductors. A possible solution could be to use a three-legged pole, which in IceTow is called "three-legged". This type of pole can provide the opportunity to have different input and output heights for the conductors, which can facilitate situations with different height requirements.  [Correct document and file path referencing]
Is there a program for dimensioning wooden poles?	Yes, there is a program called JBM.Stolpdimensionering that is used to dimension wooden poles.  [Correct document and file path referencing]
How do you calculate if the cross-arm can withstand the loads?	To calculate whether the cross-arm can withstand the loads, one starts by calculating the bending momentum that arise due to the vertical and horizontal forces acting on the cross-arm. These momentum forces are calculated by multiplying the force by the distance from the point of application of the force to the pole leg. Then the elastic bending resistance of the cross-arm is used to calculate the bending stress. The bending stress must not exceed the maximum allowable stress for the cross-arm. For an HEA cross-arm (vertical or horizontal) or a UPE cross-arm, the basic bending stress formula is used which is the bending momentum divided by the elastic bending resistance of the cross-arm. According to the document, the maximum allowable stress for a cross-arm is 214 newtons per square millimeter. One then selects the cross-arm from the column data where the calculated stress is less than the maximum permitted stress.  [Correct document and file path referencing]

Table 5: Questions and answers from the proof-of-concept knowledge tool.

The results demonstrate the technology’s ability to both locate the relevant document and retrieve the relevant information from it. This demonstrates the potential for developing a large scale AI-driven knowledge tool for power line designers. Although this study providing limited results on the precision and recall, the results were considered as satisfactory by the author of this work when testing the system. More research on these specific metrics should be investigated, especially for systems with a higher number for documents. The questions used for this demonstration shows how the technology is able to retrieve the relevant knowledge for various types of questions for power line design. The last example in table 6 demonstrates how the knowledge from the line loading lengths analysis can be transferred easily to a junior engineer stuck in a work task.

User question	AI response
How do you calculate the top diameter when dimensioning wooden poles?	<p>To calculate the top diameter when dimensioning wooden poles, you can use the smallest possible ground diameter as a starting point and then apply the conicity formula. The conicity for poles is a constant that describes how much the pole’s diameter decreases per meter along the pole’s height. The formula for calculating the top diameter based on the ground strap diameter and the total height of the pole above the ground is:</p> $\text{top diameter} = \text{ground diameter} + (\text{total height of post above ground} * \text{conicity} * 100)$ <p>Where the conicity is 0.01 meters per meter (m/m), which is a standard value used to describe how much the diameter of the pole decreases per meter along the height of the post.</p> <p>[Correct document and file path referencing]</p>
When conducting pole placement, what maximum values for $a_v$ and $a_h$ should be used for conductor line 910 Solros?	<p>For conductor line 910 Solros, the maximum values for the distance between the poles in the horizontal and vertical direction (<math>a_v</math> and <math>a_h</math>) should be taken into account as shown in the supplementary analysis carried out with JBM-Stolpdimensionering. This analysis showed that tree-topped pole structures can handle a higher <math>a_h</math> value than similar steel-topped structures, and that the ADSS pole can handle a higher <math>a_v</math> value compared to the other structures. The exact maximum values of <math>a_v</math> and <math>a_h</math> for conductor line 910 Solros are not specified in the document, but it appears that the 3-guyed constructions are superior for the dimensioning, which can be a guide for pole placement in future projects.</p> <p>[Correct document and file path referencing]</p>

Table 6: Questions and answers from the proof-of-concept knowledge tool.

### 6.3 LLM evaluation on power line design knowledge

The study on comparing ChatGPT-4's answers with junior power line designers showed that ChatGPT-4 achieved an overall average ranking similar to the junior designers as shown in Figure 22, where 1 being the best and 7 the worst. All the participants answers to the questions Q1-Q5 listed below this paragraph can be seen in the appendix. Figure 21 show the difference in ranking between the two experts. The validation for question 1, 4 and 5 gave a fairly similar ranking score. But question 2 and especially 3 showed a higher difference.

- Q1.** According to the text, name one primary benefit and one primary trade-off of adding stays on a pole.
- Q2.** How does the angle  $\gamma$  influence the calculated minimum required diameter of the stay?
- Q3.** How does the safety factor for the stay influence the minimum required area of the stay?
- Q4.** Why is the formula for the vertical force from one stay on the pole different compared to the formula with two stays on a pole?
- Q5.** In the text, what method is used to derive the formula that describes the minimum required thickness of the stay?

Most of the participants answered correctly for most answers, but some answers were too short, too unclear or only partially correct according to the experts. For question 2 which resulted in a high difference in ranking between the experts, ChatGPT-4 came to the correct conclusion but made a partial logical error in its explanation. For question 3, both experts noted that ChatGPT-4 gave a correct answer. However, due to the high number of correct answers for that question, the experts ultimately ranked responses based on their personal preferences regarding for example answer length. The average time taken for the human participants with the test was 27 minutes.

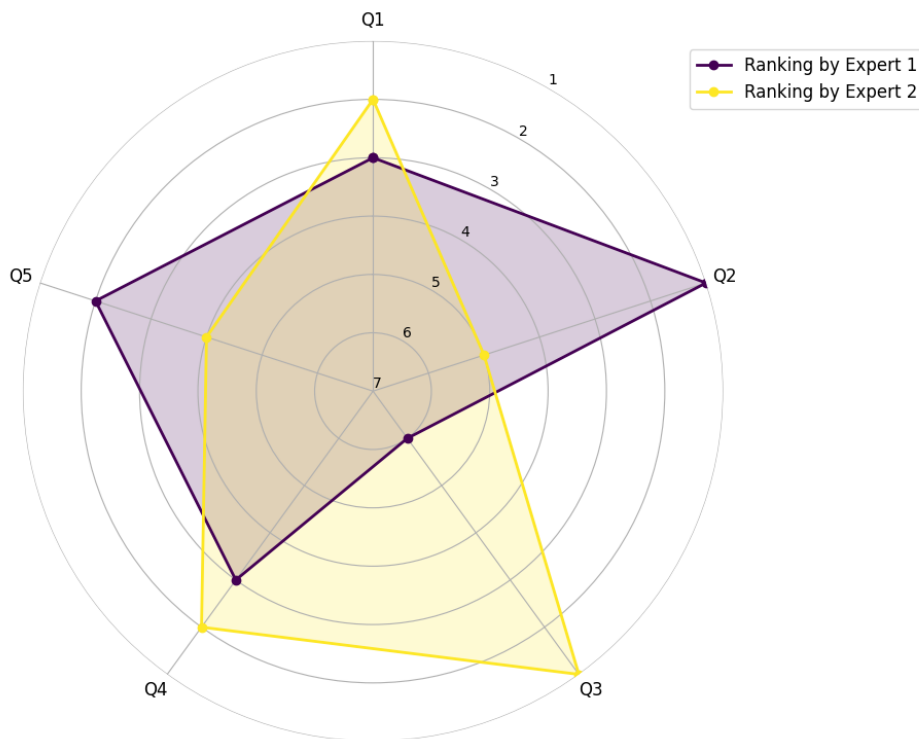


Figure 21: Ranking of ChatGPT-4's responses compared to the junior engineer responses on retrieving information about dimensioning stays. Ranking 1 being the best and 7 the worst.

ChatGPT-4 gave correct answers for all the questions but with partial errors in question 2 and 5. For question 2, it responded that an increase in  $\gamma$  would lead to a bigger vertical force on the pole when in fact the vertical force should decrease (See the appendix for all answers). But the answer reached a correct conclusion which led to one of the experts giving it a high ranking. It also gave a partial error on question 5 where it mentioned the calculation approach for the vertical force in a manner that was not relevant for this question according to one of the experts.



Figure 22: This figure illustrates the rankings assigned to the responses generated by a language model and junior designer engineers across five evaluation questions (Q1 to Q5). Each response was assessed by two experts. The responses were ranked on a scale of 1 to 7, with 1 denoting the most preferred response and 7 the least.

## 7 Discussion and key insights

This research have found that LLM have the ability to retrieve complex design knowledge in power line design. These results shed light on the research question: "Can a state-of-the-art large language model retrieve complex design information from a power line design engineering document with a satisfactory accuracy?" The results and insights from this work indicate that the potential for mitigating the loss of the senior knowledge is high with such an AI-driven knowledge tool.

Guidelines for responsible AI projects has been established in the conceptual framework for generative artificial intelligence [38]. This framework highlights the importance of communicating the projects purpose and providing contextual clarity, transparency and accountability, respecting data rights and privacy, mechanism for verifying the authenticity of AI-generated content, security and robustness, bias mitigation, consider potential negative impact on jobs, encouraging public engagement and collaboration, continuously evolving the project, showing awareness of ethical issues, assessing the trade-offs and benefits, balancing the benefits and trade-offs ethically in decision-making, building in ethics into the design of the systems, clear explanations on how the AI systems work, taking feedback from users and reviewing the results and updates carefully to avoid negative ethical implications. The following sections delves into the potential practical implications and concerns when introducing an AI-driven knowledge tool in power line design.

### 7.1 Who gets impacted by this work?

Negative economic and social impact is one of the main ethical concerns from generative artificial intelligence [38]. AI-driven knowledge tools could for example allow junior engineers to solve problems independently. This may reduce the income for under-consultants who rely on providing help and knowledge to other companies. Additionally, potential devaluation of human interaction could increase if future engineers prefer interactions and knowledge transfer from AI-tools rather then contacting real life experts, especially if these tools will provide more helpful and faster responses [38].

EBR expert Peter Silverhjarta believes the potential impact of AI on the power line industry raises questions far beyond the industry itself [39]. This would involve questions regarding safety nets for welfare such as the Swedish A-kassa etc. Additionally, Silverhjarta saw risks for consultant organizations like NEKTAB due to the potential reduce in demand from this new technology.

Power line design company's efficiencies that increases substantially due to new AI technologies might result in a reduction in demand for both existing consultants and new hires. This might result in a high negative and social impact due to loss of income and potential increase in societal unemployment.

### 7.2 The drawback of instant knowledge and potential loss of learning

Erosion of human skills is another main ethical concern from generative artificial intelligence [38]. One of the main limitations of a well performing knowledge tool is the potential loss of learning for engineers in their work. Work experience is often gained from trial and error or by learning how to look for the relevant knowledge. This experimental form of learning might reduce if many of the junior engineers problems are solved by just interacting with an AI-knowledge tool. If such a knowledge tool provides decisions for complex problems, an engineers own decision making ability might be weakened. Many future junior engineers will have experience in using AI-tutors for help with their studies [38]. Therefore, these drawbacks might already have been starting before beginning employment in the work force.

### 7.3 Safe and unsafe uses

Ensuring data security when introducing new technologies into high stakes infrastructure companies is essential for national security. Therefore an AI-driven knowledge tool within power line design must have certain limitations and access restrictions. The tool should not conduct decision making for the engineer risking severe faults in high risk systems developed by the engineer. Only providing quick access to relevant knowledge should be the scope for the tool. Additionally, user access restrictions must be enforced if the tool is trained or given access to confidential information, otherwise risking giving classified information to an unwanted third party user.

EBR expert Peter Silverhjärta emphasises the importance of safety considerations when developing AI-driven knowledge tools [39]. He advocates for companies to develop their own models for preserving their intellectual property and ensuring control over how the models generate responses.

The European parliament developed the Artificial Intelligence Act for regulating the use of AI in EU [40]. This regulation was put forward to ensure the safety of the European citizens from the potential high risks with AI technology. In these regulations, AI systems are classified with different levels of risks. High-risk AI systems fall under much stricter requirements and must establish and conduct several comprehensive security measures [41]. Whether or not an AI-driven knowledge tool for power line designers fall under a high-risk level with these new regulations is unclear and should be investigated before deploying such a tool.

## 7.4 Data-driven bias

Machines trained on data that contain bias will exhibit bias in their output if not actively mitigated. Although solving this issue being outside the scope of this thesis, it is important to highlight the potential discrimination's and unwanted stereotypes that potentially could arise from generative AI systems. Studies on how word embeddings trained on for example Google News articles has shown how such systems exhibit female/male gender stereotypes [42], while later studies also showed disturbing race and religion stereotyping resulting in negative generalizations [43]. The data in engineering design documents mainly consists of content produced by male engineers and might therefore result in outputs with bias from generative AI systems trained on that data. Strategies for mitigating or removing unwanted stereotypes have been presented in previous studies [42], [43].

## 7.5 Take-aways from the test-study of a generative language model performance compared to the junior engineers

The generative language model's expert validation rankings resulting similarly as the junior designer rankings suggest it could be a valuable AI-driven knowledge tool. If LLMs keep developing as it seems when extrapolating the historic development in Figure 6, future LLMs would likely rank even higher. The questions used for the study had different levels of complexity and the LLM answered almost entirely correct on all of them. While the LLM still not completely outperforming the junior engineers, it is understandable that the results can raise concerns when extrapolating into the future and its capabilities. The demonstration of the proof-of-concept AI knowledge tool together with these results should strengthen the argument that developing a larger scale knowledge tool for power line design is possible. But careful assessment on the potential trade-offs and benefits should be conducted before launching a potential product.

### 7.5.1 Limitations for the test-study

The first limitation is that this study was performed only with Swedish language with the LLMs. Another limitation is that the demonstrative knowledge tool precision and recall ability is not investigated. Only GPT-4 from OpenAI was used in this test-study, new powerful LLMs have been released during this work and should also be investigated.

The test study on ChatGPT-4's ability to understand design information was limited due to the number of participants. While a larger pool of participants and experts would strengthen overall validation, the limited time-frame of this thesis constrained the sample size. Future research would benefit from expanding both the participant and expert populations for more robust results. Additionally, testing the LLM on questions on various power line design subjects would also increase the study's robustness.

During the test-study, one expert identified a limitation in question 1 regarding the positives and trade-off of applying stays on a pole on mountain ground. Poles on mountain ground always require stays and it should have been mentioned in the document that not only buckling is reduced but also the bending. Lastly, the test was only performed on the design information about stays and could have yielded different results for other design topics.

## 7.6 Limitations and challenges for developing an AI-driven knowledge tool

Despite the high potential for more efficient knowledge transfer in power line design, there are big challenges and limitations to consider when developing these systems. Consider that there might be several more challenges and limitations that was not identified from this work.

### 7.6.1 Challenges in capturing senior engineer knowledge.

Insufficient knowledge provided for the AI knowledge tool will not yield enough satisfactory outputs for the many different specific situations that workers might ask questions about. Getting permission to extract some of the knowledge from NEKTAB’s database was easy due to good collaboration with the industry supervisor and the Chief Information Officer CIO of NEKTAB. And interviewing engineers within the company was a straightforward process.

But for collecting knowledge from senior experts came with a lot more challenges. Most senior experts with high experience in power line design were under consultants to NEKTAB. Their long time experience and high knowledge was considered highly valuable. Approaching these experts with the idea of extracting their knowledge into a knowledge tool based on artificial intelligence had to be made with caution, humility and respect. To make these stakeholders want to contribute with their knowledge, frameworks should be created to make them feel included, compensated or appreciated for their contribution of valuable knowledge.

<b>Possible approaches for encouraging knowledge sharing within power line design</b>	
<b>Approach</b>	<b>Description</b>
Royalty payment	Each time an expert’s knowledge (or intellectual property) is used to create the output, the expert would get compensated. This would be feasible with a referencing system like the one presented in this work.
Hourly payment	The experts would get paid hourly when conducting the interviews.
Getting their name highlighted in the output	Making sure their contribution is highlighted in the output of the knowledge tool for the user to see.
Encourage responsibility for mitigating climate change	Attempt to convince the engineers that by sharing their knowledge means they are working towards a high moral purpose.
Ask retired experts	Ask retired experts if they want to share their knowledge. There might be a higher acceptance from retired power line designers due to them no longer relying on their knowledge for their own living.

Table 7: Possible approaches for encouraging knowledge sharing within power line design.



### **7.6.2 Data security**

Utilizing API's for embedding and LLM models require giving a third party access to the company's intellectual property. Some providers claim that the data received when using the API won't be used for training their next generation of models but the risks of sharing highly classified data on national power line infrastructure is not safe due to potential information leakage. Therefore other options for creating a knowledge tool where classified information needs to be included should be investigated. Looking back at Figure 15, the Google Drive part should be changed to a local or secure cloud service to ensure a higher data security. As Silverhjärta mentioned, local open-source models might solve this issue. Therefore further research on how well open-source models can perform for a knowledge tool in power line design should be conducted. HuggingFace is a leading organisation where open-source models can be found and utilized.

### **7.6.3 Complexity in mechanical design documents**

The results from the comparison between junior power line designers to ChatGPT-4's answers point towards the mechanical design knowledge in power line design being quite difficult for the model to comprehend completely. Despite its ability to retrieve the correct information on a satisfactory level, higher intelligence in this aspect would yield more feasible use experiences for a large scale knowledge tool.

### **7.6.4 Insufficient knowledge preservation within power line design.**

NEKTAB has a well documented knowledge base within power line design, allowing them to easily scale up to a larger knowledge tool. Many companies might not have such a well documented knowledge base and might therefore have to spend a substantial time and effort in collecting or documenting the knowledge.

### **7.6.5 Importance of referencing to the source of retrieved knowledge**

Despite this work demonstrating how well GPT-4 not only retrieved the complex information but also referenced to the documents containing that information, there might be wrong outputs in some attempts. If workers get to rely on an AI-knowledge tool for their decision making, a wrong output with a hallucinated source might result in harmful outcomes in a high stakes work environment as the power line sector.

### **7.6.6 Ethical concerns**

This work has highlighted several ethical concerns and how they might be solved. The potential for the technology is high, but the potential for negative ethical implications is also high. Higher efficiency gains might result in less need for new hires or even potentially reducing the need for existing employees. The responsibility on the leaders to act ethically for humans in this industry is very important. Due to the rapid pace of this technological development as mentioned in the background, all leaders within power line design should put effort in ensuring a safe work future for existing employees.

### **7.6.7 Bias**

As mentioned in the chapter on Risks and Concerns, bias is an issue for LLMs and can result in disturbing responses. While these issues being very important to solve, the of this work did not include effort in providing methods for mitigating these problems due to the very difficult techniques and knowledge required. Nonetheless, this issue remains as a major challenge for developing an AI-driven knowledge tool. Discrimination's and disturbing generalizations from outputs with these systems have to be removed, therefore future research about this should be conducted.

## **7.7 Impact assessment on the sustainable development goals by ChatGPT (GPT-4) with author review**

The United Nations Sustainable Development Goals (SDGs) are good metrics to assess potential benefits and trade-offs from new technology or projects [44]. To further demonstrate how AI can be used for work in sustainability and energy, the chapters introduction, problem statement, objective and methodology was

provided to ChatGPT with the instructions:

”Based on the provided chapters from a master thesis document provided below, make a list of the main trade-offs and benefits on all of the 17 United Nations Sustainable Development Goals specifically from such a knowledge tool. Thesis text: [Thesis text]”. ChatGPT’s answer is shown in the tables 8 to 11 in normal text while the human author comments and contribution is shown with bold text.

Sustainable development goal	Synergy (benefit)	Trade-off
SDG1: No poverty	Improved infrastructure development through more efficient power line designs can contribute to economic development, potentially reducing poverty.	The focus on technical skills may not directly address the immediate needs of the poorest communities unless accompanied by broader access to electricity and energy. <b>The above mentioned trade-off highlights the importance of technology sharing with struggling communities power line design projects.</b>
SDG2: Zero Hunger	Enhanced energy infrastructure supports agricultural innovations and food storage solutions, indirectly contributing to food security.	Direct contributions to reducing hunger are limited, with resources potentially diverted from immediate agricultural needs. <b>It is not entirely clear what the LLM means here. Possibly use of land from data-centers required for AI.</b>
SDG3: Good health and well-being	Reliable electricity supports healthcare facilities and services, improving health outcomes.	Requires careful consideration to avoid environmental harm from infrastructure projects that could affect community health. <b>This trade-off is not described why specifically an AI-driven knowledge tool might give this negative effect.</b>
SDG4: Quality education	The tool’s development process and its deployment can foster educational opportunities in engineering and sustainability. <b>The tool could serve as a powerful assistant for personalized learning and overcoming barriers regarding access and language, thus providing synergies to SDG4 in both power line industry and academia.</b>	May require reallocation of educational resources towards specialized engineering skills, possibly at the expense of broader educational needs. <b>While unclear exactly what ChatGPT-4 mean, it might refer to the potential loss of knowledge by exploratory learning.</b>

Table 8: Impact on the sustainable development goals 1-4 from a knowledge preservation tool for power line design. Human author comments and contributions are shown with bold text while ChatGPT’s (GPT-4) contribution is shown with normal text.

Sustainable development goal	Synergy (benefit)	Trade-off
SDG5: Gender equality	Could promote gender equality by providing equal opportunities for women in STEM fields related to energy infrastructure.	Effective contribution requires active efforts to include women and marginalized groups in these technological advancements. <b>Transparency on what data new AI-systems from for example OpenAI was trained on has not yet been disclosed. Therefore a lack of transparency exists when utilizing API's from such provider. Bias in these systems might also produce disturbing generalizations.</b>
SDG6: Clean water and sanitation	Energy infrastructure development can support water treatment and distribution systems.	Large-scale projects must be managed to prevent negative impacts on water resources. <b>Similar to the trade-off in SDG2, data centers might be what ChatGPT refers to.</b>
SDG7: Affordable and clean energy	Enhances the efficiency of clean energy infrastructure development, directly aligning with the goal of increasing access to affordable, reliable, and modern energy.	<b>No trade-offs identified.</b>
SDG8: Decent work and economic growth	Creates skilled jobs and promotes economic growth through infrastructure development.	The shift towards automation and AI could challenge traditional engineering roles, necessitating workforce retraining. <b>The purpose of an AI-driven knowledge tool would be to limit the need for long workforce retraining.</b>

Table 9: Impact on the sustainable development goals 5-8 from a knowledge preservation tool for power line design. Human author comments and contributions are shown with bold text while ChatGPT's (GPT-4) contribution is shown with normal text.

Sustainable development goal	Synergy (benefit)	Trade-off
SDG9: Industry, innovation and infrastructure	Directly supports this goal by innovating in the field of power line design and infrastructure development. <b>Allowing a broader access to knowledge and boosting novice engineers can increase innovation.</b>	<b>Potential data security risks could damage important infrastructure. Additionally, dependence on AI for decision making could potentially decrease innovation.</b>
SDG10: Reduced inequalities	Potentially reduces inequalities by democratizing access to essential engineering knowledge across different regions. <b>The knowledge tool proposed in this work might not be able to share the knowledge outside of its company due to data security and intellectual property concerns.</b>	Requires concerted efforts to ensure the equitable distribution of technology benefits.
SDG11: Sustainable cities and communities	Supports sustainable urban development through improved energy infrastructure planning.	Must be managed to align with local community needs and sustainability goals. <b>With the ability to easily add the company's own data to the tool, this could be made possible.</b>
SDG12: Responsible consumption and production	Can lead to more efficient use of materials and resources in power line construction. <b>Especially the insights from the av and ah analysis to maximize the distance between the poles.</b>	The focus on technological solutions should not overshadow the importance of reducing overall consumption. <b>This trade-off seem very generalized and outside the scope of this work.</b>

Table 10: Impact on the sustainable development goals 9-12 from a knowledge preservation tool for power line design. Human author comments and contributions are shown with bold text while ChatGPT's (GPT-4) contribution is shown with normal text.

Sustainable development goal	Synergy (benefit)	Trade-off
SDG13: Climate action	Facilitates climate action by improving the infrastructure for clean energy, directly addressing climate change mitigation.	<b>Ensuring that engineering design for sustainability would be passed on and improved, thus in the long run aiding the clean energy transition.</b>
SDG14: Life below water	Indirectly supports this goal by promoting cleaner energy sources, reducing ocean pollution from energy production.	Infrastructure projects near water bodies must minimize ecological disruptions. <b>While this being important to consider as a power line designer, it does not fit to the assessment on how the knowledge tool would affect the SDG.</b>
SDG15: Life on land	Cleaner energy infrastructure can reduce land pollution and degradation.	Careful planning is necessary to avoid habitat destruction and biodiversity loss. <b>Same as above.</b>
SDG16: Peace, justice and strong institutions	The collaborative development and deployment of such tools can support institutional innovation. <b>Collaborations between power line design companies could increase knowledge transfer.</b>	Requires transparency and accountability in technology deployment to ensure it supports justice and peace. <b>Important but very general.</b>
SDG17: Partnerships for the goals	Encourages partnerships between educational institutions, industries, and governments for sustainable development.	Effective partnerships require equitable engagement and shared objectives, which can be challenging to achieve. <b>While consultant companies rely on hourly payment, less hours might result in a conflicting interest.</b>

Table 11: Impact on the sustainable development goals 13-17 from a knowledge preservation tool for power line design. Human author comments and contributions are shown with bold text while ChatGPT’s (GPT-4) contribution is shown with normal text.

Overall, ChatGPT’s assessment provided relevant and logical synergies and trade-offs while still quite generic.

## 7.8 Contribution from this work

### 7.8.1 Potential to bridge the knowledge gap in power line design using LLMs

This work has demonstrated the potential and possibility for an AI-driven knowledge tool in power line design. As previously highlighted, the knowledge gap in power line design is large and the challenges this brings when new hires increase in rapid pace are difficult to solve. The potential for bridging the knowledge gap in this domain with AI is big and could result in significant efficiency gains in the sector. Such an increase in efficiency could lead to a faster and more sustainable electricity transition.

Another major contribution from this work has been identifying the main challenges and limitations for developing and implementing an AI-driven knowledge tool for power line design. Ranging from the data security risks, ethical implications of potential work displacement to the model response restrictions.

A better understanding of which line loading length fits which pole structures could help reduce the material use by reducing the number of power line poles. Less negative feedback loops in a project means less travel time back and to the project site and therefore less energy spent. These two factors could highly benefit the strive for a circular business model for power line design companies.

### **7.8.2 Successfully admitted Digital Futures project**

When presenting the work to the NEKTAB board, with support from the university supervisor, we pushed for the opportunity of applying to Digital Futures open innovation call for research projects. NEKTAB expressed their interest in this research and quickly committed to supporting the project. Late February 2024, Digital Futures responded that the project had been selected, and would co-sponsor the initiative. Therefore further research on developing an AI-driven knowledge tool for power line design will be conducted starting July 2024, enabling a strong industry academia collaboration for broader impact.

## 8 Conclusion

This thesis presents a pioneering investigation into the use of large language models (LLMs) for bridging the knowledge gap between experienced and novice power line designers.

### 8.1 Concluding remarks

Given the rapidly evolving energy sector, this work emphasizes the urgent need for innovative knowledge transfer methods to preserve the invaluable expertise from experts prior work experiences. Through a comprehensive literature review, the development of an instructional document on the mechanical design of power line poles, data collection, creation of a proof-of-concept AI-driven knowledge tool, and a test study using a GPT model; results and insights are presented indicating the potential for developing an AI-driven knowledge tool. The proof-of-concept knowledge tool, utilizing existing embeddings and LLMs, demonstrates how the technology can answer specific complex questions relating to power line design work and retrieve the relevant knowledge in a pool of documents. Results from the test-study show that the LLM achieves similar ranking when comparing with junior design engineers. This work also presents the main challenges and limitations for developing an AI-driven knowledge tool, along with ethical concerns, data security risks and how to approach and mitigate them. By facilitating the transfer of expertise efficiently, these tools can empower novice engineers and thereby support the sustainable transformation of the energy sector. Further research will be conducted for realizing the full benefits of such a tool with collaboration between the industry and academia. Additionally, contributions and insights on how the line loading lengths affect the dimensioning of power line design poles are presented in this work.

### 8.2 Future work

The potential for the power infrastructure sector if the knowledge gap can be bridged is high in terms of improving many SDGs, therefore future research in this subject necessary. The potential future research topics are many and the most important ones identified from this work are presented below.

Scaling up the knowledge tool requires further research into the development of a production plan due to the many parts, phases and stakeholders involved. To ensure the work security work when disruptive technologies like AI-tools are deployed, consider investigating the possibility of implementing company policies aimed for this purpose. This will be essential to ensure human work safety. The new EU AI act regulations will require AI projects to follow specific laws for ensuring for example safety and equality. Investigation of how this new act will affect the project of developing and deploying an AI knowledge tool in the power line industry is necessary. To ensuring higher data security, the project should consider using open-source LLMs. These type of models should be investigated further to assess their benefits and trade-offs compared to using APIs from leading AI companies.

Collecting knowledge from experts requires proper methods to ensure their cooperation and an ethical participation. Investigate how to make the knowledge sharing more encouraged and efficient, possibly by automating the interview process using AI.

Multi-modality for generative AI allows the use of data types beyond text, such as images, videos and audio. This functionality should be investigated further.

To promote clarity and transparency regarding the circularity and sustainability of developing a large-scale AI knowledge tool, environmental assessments and circular business models should be conducted. Reducing potential bias of AI models has not been worked on in this thesis, but should be worked on when developing the tool further.

The admitted Digital Futures project will begin in July 2024 and focus on several research aspects and scaling up the knowledge tool for power line design.

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## 9 Appendix

The following attached documents show the original Swedish notes from all the interviews conducted. The three first interviews were made together with NEKTAB engineers with the purpose of adding work experience data into the proof-of-concept AI knowledge tool. The last interview was together with the knowledge expert at EBR.

The attached original Swedish documents for the validation study (reduced white space for this report) between ChatGPT-4 and the junior engineers are shown after the interviews. The documents present how the instructions were presented to the participants in its original format and where the participants would fill in their answers. The document after the questions show the text from the chapter on stays which both ChatGPT-4 and the human participants were provided. Lastly, all respondents answers, including ChatGPT-4's marked in green, are presented in a table.

Lastly, the main required inputs for reproduction of the line wind span analysis is presented in tables. Note that the different dimensioning programs might use different calculation methods and assumptions thus possibly resulting in different pole dimensions.

# Erfarenhetsintervju för att bidra till kunskapsbanken

## Bakgrund

Intervjupersonens bakgrund inom teknik och om deras nuvarande arbetsroll?

- Byggingenjör Högscoleingenjör Örebro Universitet
- Master i hållbara konstruktionsteknik
- Kraftledningsprojektör i 6 månader på NEKTAB.

## Erfarenhet 1

- **Hög stolplast vid dimensionering** för vinkelstolpe PVA51 (0-33 gon).
- **Teori och Lösning**
- **Teori:** Stolpen ska utsättas för tryck och har hängkedjor. Om det finns lyft i stolpen, kan faserna slå i regeln.
- **Första Lösning:** Höja vinkelstolpen och sänka omkringliggande stolpar för att underlätta dimensionering. Detta är beskrivet som den bästa och billigaste lösningen.
- **Alternativa Lösningar**
- **Alternativ Stolptyp:**
  - Byta till en **PVA52** om det är för mycket lyft. PVA52 har spännkedja istället för hängkedjor men är dyrare och används oftast över 66 gon.
  - **PVA62** som ett alternativ för intervallen 33-66 gon.
- **Trebenstolpe:**
  - Omvandling till trebenstolpe om knäcklasten eller böjmomentet är för högt. Nackdelar inkluderar högre kostnad och större bredd, vilket kan vara problematiskt nära vägar eller andra begränsade utrymmen.
- **Ytterligare Överväganden**
- **Kontroll av Regeln:** Det är viktigt att kontrollera att regeln klarar av de krafter som påverkar den och inte blir underdimensionerad.

## Erfarenhet 2

### Ursprunglig Metod

### Funktionskrav:

- **Input:** En DGN-fil som innehåller alla profilblad.
- **Process:** Skapande av en PDF och en DWG för varje profilblad.
- **Steg-för-steg Process:**
  - Öppna den ursprungliga DGN-filen som innehåller alla profilblad.
  - Exportera varje profilblad till en separat DGN-fil.
  - Rensa den exporterade DGN-filen för det specifika profilbladet.
  - Exportera den rensade filen till både DWG och PDF-format.
  - Upprepa processen för varje profilblad.

#### **Designparametrar:**

- **Verktyg:** Programvara som kan hantera och exportera DGN-filer.
- **Tid:** Processen är tidskrävande på grund av de många manuella stegen.

#### **Förbättrad Metod**

##### **Funktionskrav:**

- **Input:** Samma som tidigare, en DGN-fil som innehåller alla profilblad.
- **Process:** Förbättrad effektivitet i skapandet av en PDF och en DWG för varje profilblad.
- **Steg-för-steg Process:**
  - Kopiera den ursprungliga DGN-filen för varje profilblad.
  - Rensa kopierad fil så att endast det relevanta profilbladet finns kvar.
  - Exportera den rensade filen till DWG och PDF.
  - Upprepa processen för varje profilblad.

#### **Designparametrar:**

- **Verktyg:** Samma som tidigare, men processen kräver mindre manuell hantering per profilblad.
- **Tid:** Tidsbesparing genom att minska antalet steg i processen för varje profilblad.

#### **Erfarenhet 3**

Uppgift: Skapa markprofil

Problem: z-koordinaterna hängde inte med för varje punkt.

Anledning: Hade use triangels istället för use laser scan points.

Lösning: Använd use laser scan points.

#### **Erfarenhet 4**

Uppgift: Placera en vinkelstolpe nära väg.

Problem: Avståndet mellan stag och släntkrön är för nära. Stagen får inte vara närmare än 2 meter.

Ett släntkrön är precis där ett dike börjar. Mer information finns på Trafikverkets hemsida

Standardvillkor för ledningsärenden inom vägområdet.

Lösning: Rita en släntkrönslinje i laserdatamodellen. Därefter offsets den 2 meter mot stolpen för att veta hur nära staget får vara till släntkrönet. Därefter se till att få med släntkröntslagret i plankartan också.

### **Erfarenhet 5**

Uppgift: Konstruera en ledning med 52 kV konstruktionsspänning (40 kV driftspänning).

Problem: Vilka tower geometries i Icetow. Alltså vilka slags stolpkonstruktioner som bör användas.

Förklaring:

- Beteckningar för stolpkonstruktioner. Några exempel på standardkonstruktioner för 52 kV är:
  - Vinkelstolpar:
    - PVA51
    - PVA52
    - PVA62
    - EVA51
  - Raklinjestolpar:
    - ERA51
    - PRA61
    - PÄRA51 utan stag
  - Ändstolpar:
    - PÄRA51

### **Erfarenhet 6**

Uppgiften: Stolpkontroll

Problemet: SVK stag från en stolpe gick precis där nya stolpen skulle placeras.

Lösningen: Fick flytta ut stolpen så det fanns marginaler för att kunna gräva en grop till stolpen för att den skulle kunna placeras. För att komma ut ur ledningsgatan kan man antingen flytta ut hela sträckningslinjen alternativt sätta två små vinkelstolpar före och efter den aktuella stolpen och enbart flytta ut stolpen som krockar med SVK stolpens stag.

### **Erfarenhet 7**

**Vart brukar man placera avspänningstolpar?**

# Erfarenhetsintervju för att bidra till kunskapsbanken

## Bakgrund

Intervjupersonens bakgrund inom teknik och om deras nuvarande arbetsroll?

- Farkostteknik och hållbar energiteknik.
- Kundrådgivare inom sophantering.
- 2 år på NEKTAB som kraftledningsprojektör.

## Övriga tankar:

Utmaningar:

- Att lära sig ställa rätt frågor och hur inse när det är dags att ställa en fråga.
- Sökvägar är viktigt att ha med. Kan vara klurigt att hitta bland mapparna i Uppdragsmodellen.
- Folk uppfinner hjulet igen även fast vissa sitter på den nödvändiga kunskapen/erfarenheten.

## Erfarenhet 1

Uppgift: Skapa samlingsmodell

Problem: Osäker på skalan för ortofotot. Veta exakt hur stort ortofotot ska vara.

Lösning: GIS bör veta om detta. Fråga dom. Det är viktigt att skalan blir rätt. Svårt att få ortofotona att match ihop utan att veta korrekta storleken.

## Erfarenhet 2

Uppgift: Skapa laserdata modell.

Problem: Det tar jättelång tid när laserdatamodellen skapas.

Lösning: Använd lägre densitet när man läser in laser-data filerna som man beställt. Vissa leverantörer ger mer detaljerade laserdata. Visimind brukar ge väldigt detaljerade.

## Erfarenhet 3

Uppgift: Stolpplacering i IceTow.

Problem: En stolpplats som inte blivit inmätt. Missad inmätning. Inget sonddjup eller liknande. Svårt att åka ut igen för att kontrollera i fält. Vetskap om dåligt underlag i området.

Lösning: Stolpen togs bort och närliggande stolpar flyttades närmare. Om man vet att marken är bra i områden hade man kunnat placera den där ändå.

## Erfarenhet 4

Uppgift: Stolpplacering av 52kV ledning i korsning med befintlig ledning och järnväg. Korsning med väldigt skilda höjdkrav.

Problem: Stor höjdskillnad i var faserna måste sitta. Måste vara en viss höjd ovanför järnväg. Och en viss höjd under den befintliga ledningen. Omöjligt att uppfylla kraven som ställdes från både järnvägen och befintliga ledningen. Vinkeln var också 90 grader vilket medförde väldigt belastningar.

Lösning: Löstes med en specialkonstruktion som tillät en ingångshöjd för fasen och en annan utgångshöjd för fasen. En slags tre-bensstolpe. Den heter "tre-ben" i IceTow.

### **Erfarenhet 5**

Uppgift: Bestämma nedgrävningsdjup för en stolpe.

Problem: Nedgrävningdjupen i IceTow som man får ut är bara godtyckligt.

Lösning: Efter stolpdimensioneringen tas nedgrävningsdjupen ut från EBRs tabeller om förankringskonstruktioner som kan hittas antingen i EBR-e eller uppdragsmodellen. Olika djup för komposit- och trästolpar.

### **Erfarenhet 6**

Uppgift: Dimensionering av vinkelstolpe.

Problem: Hur dimensionerar man vinkelstolpar överlag?

Lösning: På NEKTAB dimensioneras vinkelstolpar alltid med bergstag för att det är scenariot som kräver den grövsta stolpdimensionen. För om det hade visat sig att stolpplatsen inte var jord utan berg så hade stolpen kanske inte klarat av belastningarna vilket skulle kunna leda till att stolpen går sönder.

### **Erfarenhet 7**

Uppgift: Stolpplacering.

Problem: Hur veta var det borde vara en kompositstolpe istället för trästolpe.

Lösning:

- Svåråtkomlig stolpe för reparation och underhåll.
- Om den står för nära vatten. Trästolpar impregneras med kreosot som är giftigt och inte får användas nära vattendrag.
- Om det är väldigt blött i marken som exempelvis sankmark.
- Om stolpen blir väldigt hög. Gränsen är upp till beställaren. Trästolpsmarknaden för tillfället kan också påverka. Leveranstiden på trästolpar över 20 meter kan vara över ett år.



# Erfarenhetsintervju för att bidra till kunskapsbanken

## Bakgrund

Intervjupersonens bakgrund inom teknik och om deras nuvarande arbetsroll?

- Elektroteknik högskola Väst
  - 180 HP
  - Inriktning Elkraft.
  - Praktik på Vattenfall som montör.
  - Praktik på Vattenfall distribution. Virtuellt system.
- Svenska kraftnät i 3 år som teknikstöd och projektering.
- Nu kraftledningsprojektor på Nektab i 10 månader.

## Tankar:

Normer.

Kunder har dokument som beskriver hur saker ska vara utförda. Finns mycket detaljer i dom!

Hur tycker Vattenfall hur man ska skarva linor osv...

Vilka riktlinjer går igenom det här???

Kunder stör sig ofta på att vi inte följer riktlinjer. Dom har inte alltid koll på det själva. Dom borde tillåta att dokumenten används.

Vilka projektnummer finns i det här området? Snabbt kunna få svaret. Det vore till stor hjälp.

## Erfarenhet 1

Uppgift: Har kunden eller beställaren speciella krav på projekteringen.

Problem: Osäker på kundens eller beställarens kravställning.

Lösning: Se tekniska riktlinjer via kundens hemsida eller i uppdragsmodellen här: REMOVED

Tänk på att deras riktlinjer uppdateras löpande och att de som ligger i uppdragsmodellen kanske inte längre stämmer. Om inlogg behövs till kundens hemsida så kan du fråga projektledaren.

## Erfarenhet 2

Uppgift: Förnya ledning parallellt med annan ledning.

Problem: Vad behöver jag ta hänsyn till?

Lösning: Exempel på saker att ta hänsyn till:

- Olika kunder/beställare kan ha olika krav vad gäller avstånd osv.
- Måste ta hänsyn till att befintlig konstruktion kan skilja sig mot den nya. Exempelvis att vinkelstolpar som är syskade kanske är tänkt att vara stagade. Dessa nya vinkelstolpar behöver förmodligen anpassas eller flyttas för att stagen hamnar ivägen.

- Vid reinvestering (byter ut hela ledningen) kan spänningsnivån ökas. Detta kan innebära andra krav gällande avstånd.
- Vid annan dimension på ledare kan det vara svårt att hålla samma avstånd mellan stolpar som den befintliga. Vilket kan medföra problem för ny placering av vissa vinklar i terräng. En lösning kan vara att man i tidigt skede ser att det behövs en special konstruktion för att klara av belastningen på ursprunglig placering. Om inte det räcker med en grövre stolpdiameter finns det alternativ som kompositstolpe, stål- fackverkskonstruktion. Men man vill generellt undvika sådana specialkonstruktioner pga. den högre kostnaden.
- Var noga med att mäta in den parallella ledningen och den befintliga i tidigt skede. Mer instruktion om detta finns i Uppdragsmodellen.

### **Erfarenhet 3**

Uppgift: Ta hänsyn till projekt i omgven.

Problem: Behöver mitt projekt anpassa sig till något annat närliggande projekt? Vad ska man tänka på vid projektering?

Lösning: Denna infor finns oftast hos beställaren men det är bra som konsult att visa hänsyn till potentiella närliggande projekt. Man kan ta ett möte eller stämma av med ansvariga för det andra projektet.

# Intervju med kunskapsexpert inom kraftledningskonstruktion

## **EBR:s Arbete med Kraftledningsprojektering:**

- Bygger på en encyklopedi med runt 300 handböcker.
- Innehåller data om arbetsmetoder, säkerhetsanvisningar, tidsåtgång m.m.
- Används av alla företag i branschen, drivs av branschens intresseorganisation med 400 koncerner.
- I symbios med Svensk Elstandard (SEK) men med striktare krav hos EBR än standarden.

## **Metoder för Kunskapsdelning:**

- Övergång från pappersbibliotek till mer digitaliserat format, kvarhåller dock pappersformat för säkerhet.
- Ingen databas användning; SMS-system nämns som kommunikationsmedel.

## **Historisk Utveckling:**

- EBR började skapas i slutet av 1960-talet med avtal som dateras tillbaka till omkring 1972.
- Identifierar ett kunskapsgap.

## **Implementering av Ny Teknik:**

- Idéer om att skapa en egen "ChatEBR" för att säkra användningen.

## **Etiska Aspekter:**

- Peter anser inte att experterna som delar med sig av kunskap ska kompenseras; mycket kunskap har redan gått förlorad.
- Konsultarbete kan minska på grund av ny teknik vilket kan vara en nackdel för konsultföretag som NEKTAB.

## **Säkerhet:**

- Viktigt att kontrollera modellens svar, speciellt gällande säkerhetsarbete.

## **Beslutsprocess:**

- EBR kommitté tar emot förslag men äger inga medel själva.
- Ingen fastställd mekanism för att välja AI-modeller; potentiellt projekt diskuteras.

## **Expert Intuition:**

- Vikten av erfarenhet och praktisk kunskap betonas.
- Vissa arbetslag är upp till fyra gånger effektivare på grund av erfarenhet och kunskap.

## **Användning av Historisk Data:**

- Historisk data används för underhåll och reparation.
- Vikten av att integrera all historisk data till AI-system.

## **Branschrelationer:**

- EBR är strikta med sin information och skulle agera rättsligt om deras material används olovligen.
- Förväntar att fler energiföretag kommer att utveckla egna system inom de närmaste tre åren.

## Instruktioner

Din uppgift är att svara på frågor baserat på informationen i texten nedan. Svara med maximalt 50 ord för varje fråga.

Totalt 5 frågor med en på varje sida i detta dokument.

Jobba endast med en fråga i taget.

Berätta för mig när du börjar med en fråga och när du vill gå vidare till nästa.

### Fråga 1

Enligt texten, nämn en fördel och en nackdel med att använda stag på en raklinjestolpe på berg.

Ditt svar här:

### Fråga 2

Hur påverkar vinkel  $\gamma$  den beräknade minsta tillåtna diametern för stag?

Ditt svar här:

### Fråga 3

Hur påverkar materialfaktorn för stagen den minsta tillåtna beräknade arean för stag?

Ditt svar här:

### Fråga 4

Varför är formeln för den vertikala kraften från ett stag på en stolpe annorlunda jämfört med formeln med två stag på en stolpe?

Ditt svar här:

### Fråga 5

Enligt texten, vilken metod används för att härleda formeln som beskriver den minsta tillåtna tjockleken av ett stag?

Ditt svar här:

# 1 Stagkrafter

## 1.1 Horisontella och vertikala krafter från stag

För att motverka att stolparna faller omkull, böjs eller knäcks väljer man ibland att staga stolpen.

### 1.1.1 Bergstag

En stolpe som står på berg kan inte monteras djupt i jorden som för en jordstolpe, därför behövs bergstag för att stabilisera den. Bergstag placeras oftast några meter under regeln. Dessa stag motverkar knäckning för stolpen då stagen gör att man kan räkna med andra knäckfall. Att staga en stolpe ger uppkomst till en ny vertikal kraft från stagen som påverkar stolpens knäcklast. Men eftersom knäcklängden mellan staginfastningen och marken är kortare, tillåts den vertikala kraften vara större än om stagets infästning skulle sitta vid toppen av stolpen.

## 1.2 Räkna ut den maximala dragkraften i staglinan

Hållfasthet i brottgränstillstånd för stag är:

$$F_{ud} = \frac{F_{uk}}{y_{e1} \cdot S_{stag}} [MPa]$$

Staglinans normerande brottlast:

$$F_{uk} = 1400 [N/mm^2 = MPa]$$

Som tidigare nämnt är säkerhetsfaktorn för konstant last:

$$y_{e1} = 1,1$$

Materialfaktor för stag:

$$S_{stag} = 1,55$$

(Svensk Elstandard, Normer för Sverige, u.d.)

## 1.3 Härledning av vertikala stagkraften $V_S$

Ostagad stolpe:

$$V_S = 0 \text{ [N]}$$

Enkelstagad stolpe:

Här används trigonometriska samband tillsammans med momentjämvikt för att härleda fram  $V_S$  för en enkelstagad stolpe:

$$\frac{H_S}{V_S} = \tan\gamma \rightarrow \left\{ \tan\gamma = \frac{\sin\gamma}{\cos\gamma} \right\} \rightarrow V_S = H_S \cdot \frac{\cos\gamma}{\sin\gamma}$$

Flerstagad stolpe:

På liknande vis fast i 3 dimensioner, med hänsyn till krafterna som uppstår i riktningen  $\alpha$ , härleds  $V_S$  för flerstagad stolpe:

Först från sidan:

$$\tan\gamma = \frac{V_{S_{xy}}}{V_S} \rightarrow V_{S_{xy}} = V_S \tan\gamma$$

Nu är det viktigt att beakta att  $V_{S_{xy}}$  är helt och hållet en horisontal kraft, eftersom den är en horisontal komponentuppdelning av  $V_S$ . Sedan från ovan:

$$\cos\alpha = \frac{V_{S_x}}{V_{S_{xy}}} \rightarrow V_{S_x} = V_{S_{xy}} \cos\alpha$$

Sätter in ekvationen för  $V_{S_{xy}}$ :

$$V_{S_x} = V_{S_{xy}} \cos\alpha \rightarrow \left\{ V_{S_{xy}} = V_S \tan\gamma \right\} \rightarrow V_{S_x} = V_S \tan\gamma \cos\alpha$$

Nu har vi ekvationen för den vertikala kraften från stagen med hänsyn till båda vinklarna så krafterna hamnar i samma plan. Newtons 1:a lag (kraftjämvikt) säger att  $V_{S_x} = H_S$ .

Detta ger:

$$V_{S_x} = H_S \rightarrow V_S \tan\gamma \cos\alpha = H_S \rightarrow V_S = \frac{H_S}{\cos\alpha \cdot \tan\gamma} \therefore$$

## Beräkna stagarean

Och med hjälp av att vi vet hållfastheten i brottgränstillstånd  $F_{ud}$  [N/mm<sup>2</sup>] kan areaformeln härledas via dimensionsanalys:

$$[\text{mm}^2] = \frac{[\text{N}]}{[\text{N}/\text{mm}^2]} \rightarrow A_{stag} = \frac{R_S}{F_{ud}} [\text{mm}^2]$$

Där arean  $A_{stag}$  beräknas för alla olika stag med respektive resulterande stagkrafter  $R_S$ .

<b>Answers to all the test questions in the validation study. ChatGPT-4 answers marked with green.</b>
<b>Question 1 all answers:</b>
En fördel är att bergstag motverkar knäckning för stolpen. Däremot ger det en extra vertikal kraft på stolpen som kan vara en nackdel. Anledningen till att den motverkar knäckning är att längden för knäckfallet blir kortare.
En fördel med att använda bergstag är att stagen motverkar knäckning. En nackdel är att det uppkommer en vertikal kraft från stagen.
Fördel: Bergstag stabiliserar stolpen på berg, där djup montering inte är möjlig, genom att motverka knäckning och tillåta större vertikal kraft. Nackdel: Skapar en ny vertikal kraft som påverkar stolpens knäcklast, vilket kräver noggrann beräkning för att säkerställa stabilitet.
Fördel: Motverkar knäckning
Nackdel: Ger uppkomst till en ny vertikal kraft vilken påverkar knäcklasten
Fördel: Stabiliserar stolpen och motverkar knäckning
Nackdel: Ger upphov till en ny vertikal last
Fördelen med att bergstaga är att stabilisera stolpen från att t ex falla omkull. Nackdelen är att vid stagning uppkommer det en vertikal kraft. Den vertikala kraften leder till ett nytt dimensioneringsmoment då du får två olika knäckfall på stolpen. Knäckfall 1 som uppstår mellan stolpens topp och ner till staget och knäckfall 2 från staget ner till marken.
Nackdel= Stag kan vara ivägen för t.ex vägar och andra konflikter. Knäcklasten blir dock påverkad av att stagen tillkommer på stolpen, men blir inte lika illa som om de skulle sitta vid regeln.
Fördel= Man får lägre knäcklast med stagen placerade under regeln
<b>Question 2 all answers:</b>
Den minsta tillåtna diametern för stag minskar med ökad vinkel $\gamma$ .
Det påverkar de horisontella och vertikala laster på stagförankringen, så beroende på vilken lutningen så kommer antingen den horisontella eller vertikala lasten öka.
Dragkraften som uppstår i stolpen p ga vind eller liknande vill man motverka kraften genom en kraft $H_s$ som baseras på vinkeln $\gamma$ . $\gamma$ redogör staglutningen och högre staglutning bidrar till lägre diameter på staget.
För att beräkna stagarean behöver man resulterande stagkrafterna $R_s$ och hållfastheten i brottgränstillstånd, $F_{ud}$ . $F_{ud}$ är känt medan de resulterande stagkrafterna beräknas med hjälp av vinkeln $\gamma$ . I 3 dimensioner, som man behöver beakta för flerstagade stolpar tillkommer en till vinkel, $\alpha$ . För 2D är formeln för stagkrafterna $H_s/V_s = \tan(\gamma)$ , detta innebär att båda kraftkomponenterna beror på samma term men inverterat. Detta innebär att kraftresultanten av dessa är konstant. Vinkeln $\gamma$ kommer däremot bestämma hur stora vertikala och horisontella krafterna är.
Större $\gamma$ --> större kraft vertikalt
Större vinkel -> större krafter på stolpen åt olika håll -> kan behövas större area

Vinkeln  $\gamma$  påverkar den beräknade minsta tillåtna diametern för stag genom att bestämma förhållandet mellan horisontella och vertikala krafter. En ökning av vinkeln  $\gamma$  leder till en ökad vertikal kraft från staget, vilket kan minska den nödvändiga stagarean och därmed möjliggöra en mindre stagdiameter för att uppnå samma hållfasthetskrav.

#### Question 3 all answers:

Arean av stag beror på hållfasthet i brottgränstillstånd  $F_{ud}$  och resulterande krafter från stag,  $R_s$  enligt följande formel  $A_{stag} = R_s / F_{ud}$ .  $F_{ud}$  beräknas med hjälp av staglinans nominella brottlast,  $F_{uk}$ , säkerhetsfaktorn för konstant last,  $\gamma_{e1}$  och materialfaktor för stag,  $S_{stag}$ . Dessa samspelar enligt följande formel,  $F_{ud} = F_{uk} / (\gamma_{e1} * S_{stag})$ . Detta innebär att ett ökande materialfaktor ger en minskad brottgränstillstånd. Vilket i sin tur leder till ett ökat minsta stag area.

Då säkerhetsfaktorer härstammar från dynamiska tester brukar de representera 95%ilen. Dvs att vid tilltänkt last,  $F_{uk}$  kommer det reduceras med en materialfaktor. Detta kommer därefter leda till att vid dimensionering av stagarea bli en högre tillåten area för stag då  $A_{stag} = R_s / F_{ud}$

Ju större materialfaktor för staget ju mindre brottgränsen får staget i MPa. Vilket kan resultera i tjockare area på staget för att klara lasterna.

Materialfaktorn för stagen ( $S_{stag}$ ) påverkar den minsta tillåtna beräknade arean för stag genom att ingå i beräkningen av hållfastheten i brottgränstillstånd ( $F_{ud}$ ). Ju högre materialfaktor, desto lägre blir  $F_{ud}$ , vilket ökar den beräknade arean  $A_{stag}$  för att uppnå erforderlig hållfasthet.

Om materialfaktorn ökar minskar hållfastheten i brottgränstillstånd, vilket gör att stagarean ökar.

Större materialfaktor ger en lägre hållfasthet i brottgränstillstånd -->  $F_{ud}$  blir mindre vilket ger ett behov för större area på staget

Större  $S_{stag}$  -> mindre  $F_{ud}$  -> Större  $A_{stag}$

#### Question 4 all answers:

Det beror på att stagen går åt olika håll, vilket inte uppstår när du har stag på en stolpe.

Eftersom vid enkelstagad stolpe tar staget enbart upp de horisontella krafterna från "motsatt riktning". Vid flerstagad stolpe(2+) kan de horisontella krafterna tas upp i fler riktningar (tänk att stag är motreaktion av de horisontella lasterna som stolpen utsätts för).

Formeln för den vertikala kraften från ett stag på en stolpe använder trigonometriska samband för att härleda kraften baserat på stagets vinkel mot marken. För två stag på en stolpe, tar formeln även hänsyn till 3D-effekter och krafter i olika riktningar ( $\alpha$  och  $\gamma$ ), vilket gör att den måste beakta horisontella komponentuppdelningar och kraftjämvikt i fler dimensioner. Detta komplexitetsskikt gör formeln annorlunda.

För en enkelstagad stolpe räknas den vertikala kraften från ett håll, för en stolpe med två stag beräknas den i 3 dimensioner.

Man måste räkna i 3 dimensioner istället för 2

När det bara är ett stag finns det bara en vinkel som påverkar kraftkomponenterna, gamma. Då är stagen satt så att det kan beaktas som ett 2D system med en rak stolpe och ett stag som går i en vinkel neråt. Vid två stag kommer båda stagen att fästas i samma punkt och att även vara vinklade med avseende till varandra och stolpen. Därför tillkommer en extra vinkel, alpha, som också påverkar kraftresultanterna.



<b>No stays ADSS pole</b>		
av	10-280	m
ah	10-280	m
an	160	m
Ground to beam	17	m
Conductor	AL59 910 Solros	mm <sup>2</sup>
Top line	ADSS 209	mm <sup>2</sup>
Mountain stays	None	
Mountain stays elevation	None	degrees
Distance from stays to beam	None	m
Steel top	None	
Mountain stays spread	None	degrees
Beam weight	289	kg
Pole part under ground	2	m
Insulator length	1.569	m
Insulator weight	51	kg
Distance from conductor to pole leg	2.25	m
<b>No stays steel top pole</b>		
av	10-280	m
ah	10-280	m
an	160	m
Ground to beam	17	m
Conductor	AL59 910 Solros	mm <sup>2</sup>
Top line	FeAl 241 Atle	mm <sup>2</sup>
Mountain stays	None	
Mountain stays elevation	None	degrees
Distance from stays to beam	None	m
Steel top	Yes	
Mountain stays spread	None	degrees
Beam weight	700	kg
Pole part under ground	2	m
Insulator length	1.828	m
Insulator weight	47	kg
Distance from conductor to pole leg	2.5	m
<b>No stays wood pole</b>		
av	10-280	m
ah	10-280	m
an	160	m
Ground to beam	FeAl 241 Atle	m
Conductor	AL59 910 Solros	mm <sup>2</sup>
Top line	ADSS 209	mm <sup>2</sup>
Mountain stays	None	
Mountain stays elevation	None	degrees
Distance from stays to beam	None	m
Steel top	None	

Mountain stays spread	None	degrees
Beam weight	700	kg
Pole part under ground	2	m
Insulator length	1.828	m
Insulator weight	47	kg
Distance from conductor to pole leg	2.5	m
<b>3-stayed ADSS pole</b>		
av	10-280	m
ah	10-280	m
an	160	m
Ground to beam	17	m
Conductor	AL59 910 Solros	mm <sup>2</sup>
Top line	ADSS 209	mm <sup>2</sup>
Mountain stays	Yes	
Mountain stays elevation	36	degrees
Distance from stays to beam	3	m
Steel top	None	
Mountain stays spread	60	degrees
Beam weight	289	kg
Pole part under ground	2	m
Insulator length	1.569	m
Insulator weight	51	kg
Distance from conductor to pole leg	2.25	m
<b>3-stayed steel top pole</b>		
av	10-280	m
ah	10-280	m
an	160	m
Ground to beam	17	m
Conductor	AL59 910 Solros	mm <sup>2</sup>
Top line	FeAl 241 Atle	mm <sup>2</sup>
Mountain stays	Yes	
Mountain stays elevation	36	degrees
Distance from stays to beam	3	m
Steel top	Yes	
Mountain stays spread	60	degrees
Beam weight	700	kg
Pole part under ground	2	m
Insulator length	1.828	m
Insulator weight	47	kg
Distance from conductor to pole leg	2.5	m
<b>3-stayed wood pole</b>		
av	10-280	m
ah	10-280	m
an	160	m
Ground to beam	FeAl 241 Atle	m

Conductor	AL59 910 Solros	mm <sup>2</sup>
Top line	ADSS 209	mm <sup>2</sup>
Mountain stays	Yes	
Mountain stays elevation	36	degrees
Distance from stays to beam	3	m
Steel top	None	
Mountain stays spread	60	degrees
Beam weight	700	kg
Pole part under ground	2	m
Insulator length	1.828	m
Insulator weight	47	kg
Distance from conductor to pole leg	2.5	m
<b>General</b>		
Tension for ATLE	70	MPa
Tension for ADSS	80	MPa
Tension for Solros	45	MPa
Number of pole legs	2	
Number of top lines	2	
Number of conductors	2	
Distance from bead to top line	2	m