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Bachelorthesis

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Enhanced Smart Grid Engineering using Machine Learning

Fakultät Technik und Informatik
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Faculty of Engineering and Computer Science
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Enhanced Smart Grid Engineering using Machine Learning

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for the Bachelor of Science degree programme
Renewable Energysystems and Energymanagement
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Enhanced Smart Grid Engineering using Machine Learning

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Abstract

The global warming as the cause for the expansion of renewable energies, forces the smart grid engineering process into an enhanced complexity. Within this thesis, a scientific investigation to improve this process with the usage of machine learning is pursued. Hereby three concepts are evaluated based on the state of the art and one prototypical realized. The final assessment indicates current and future application possibilities of machine learning in the smart grid domain.

Marcel Eckhard Otte

Titel der Arbeit

Erweiterung des Entwicklungsprozesses durch maschinelles Lernen im intelligenten Stromsystem

Stichworte

Regenerative Energiesysteme, Intelligentes Stromnetz, Künstliche Intelligenz, Maschienelles Lernen, Unterstützdene System

Kurzzusammenfassung

Die globale Erwärmung als Auslöser für den Ausbau von regenerativen Energiequellen treibt den Entwicklungsprozess im Energiesystem in seiner Komplexität an. Eine wissenschaftliche Auseinandersetzung mit dem Ziel diesen Prozess auf Grundlage von maschinellem Lernen erweiternd zu optimieren, wird in dieser Thesis verfolgt. Dabei werden drei Konzepte, basierend auf dem Stand der Technik evaluiert und eins durch einen Prototypen realisiert. Eine abschließende Bewertung zeigt die Einsatzmöglichkeiten von maschinellem Lernen im aktuellen und zukünftigen intelligenten Stromsystem auf.

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1. Introduction

Global warming and the resulting impact on the environment is the major challenge in the pre-industrial world (United Nations (2016)). As a consequence 196 member states of the United Nations Framework Convention on Climate Change (UNFCCC) have expressed their willingness to prevent the global development of the climate change in the Paris Climate Agreement (UNFCC (2015)). The Intergovernmental Panel on Climate Change (2018) specify "*Limiting global warming to 1.5 $^\circ$C will require substantial societal and technological transformations*". They point out that one partial solution is a sustainable energy supply.

However, integrating renewable energies into the traditional power systems for a green energy supply leads to a paradigm change (Liserre et al. (2010)), which has to be scoped by research and industry. Considering volatile renewable generators, a strong coupling to the weather as an unalterably dependency takes place in the modern power system. With the so called smart grid, the integration of these renewable energies into the power system, by challenging the encountered issues with new technology approaches, is faced (Hossain et al. (2016)).

While new methods for the whole electrical energy domain emerge, the complexity of the engineering process is, with the investigation of new business models, interoperability approaches, stakeholders and technological achievements, enlarged as well. To tackle this issues, this thesis deals with the question on how the engineering process from the design specification to the validation of new approaches can be improved by machine learning and related artificial intelligence techniques.

1.1. Renewable Energies and their Impact on the Power System

Before the evolution of the power systems in the 20th century was rolled out, the traditional power systems scoped the four different operations "electricity generation", "electricity transmission", "electricity distribution" and "electricity control" in an overall context as well as in partly investigated operation fields on a centralized, one-way communicating, hierarchical, electromechanical concept Fang et al. (2012). However, providing a reliable power system, while integrating renewable energies, where their physical behaviour is strongly coupled to uncontrollable dependencies, like weather conditions and forecasting, leads to new technological approaches which has to be integrated in the conventional power grid. To go more into detail, while considering the volatile generation as well, smart homes are good examples to point out the new technological achievements and requirements. A highly sophisticated smart home, with a decentralized power plant (i.e. photovoltaic), at itself pursues the ability to consume and generate energy effectively. Additionally, these homes are able to deliver flexibilities, act as decentralized generation systems or as a classical load, whereby a bidirectional communication and power flow exchange with the grid has to be provided. With these requirements, two aspects as key changes of the modern intelligent grid are pointed out in the contrast to the traditional grid (Farhangi (2010)). Specifying the development, with the so called smart meter such a new technology roll out is represented to provide the advanced interoperability topic between stakeholders, sensors and actors (Depuru et al. (2011)). As outlined in Figure 1.1 a smart grid overview, which considers the integration of new emerged technologies (i.e. electric vehicles, storage systems, power plants (onshore/offshore) as well as smart homes) and the existing traditional technologies (electrical infrastructure, industries, conventional power plants and communication infrastructures) has to scope the consumer as the core of the power system.

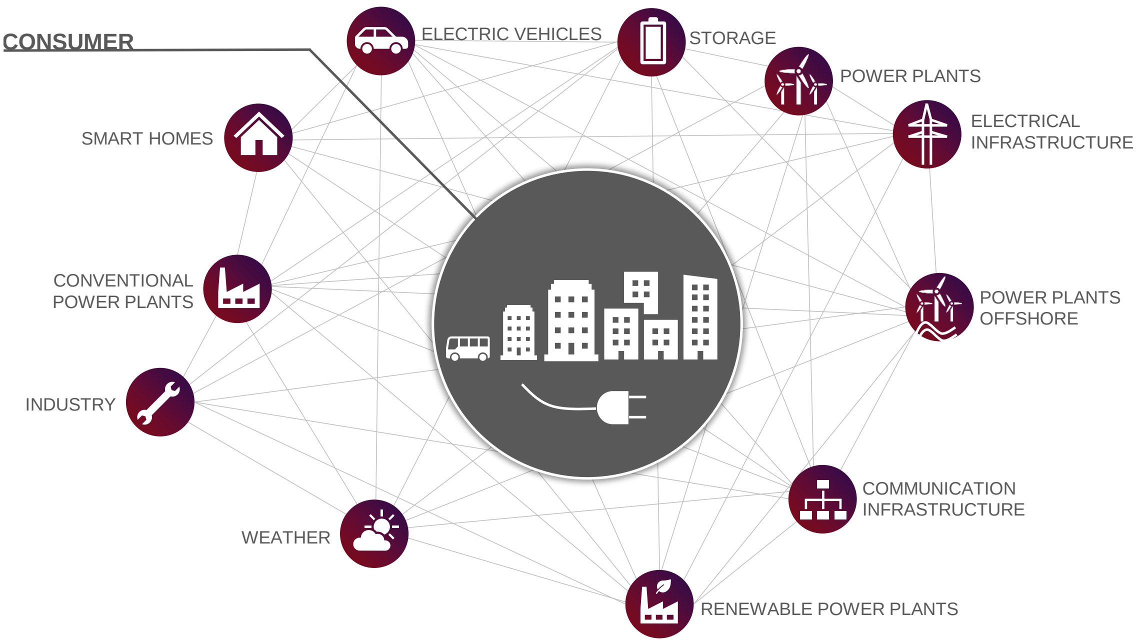


Figure 1.1.: A smart grid network overview with the most significant dependencies, technologies and the consumer as the core of the power system

1.2. Problem Definition and Research Question

As introduced the impact of the renewable energies needs to be considered in the current smart grid engineering process, whereby new challenges needs to be investigated. This thesis addresses these problems by resolving the question on how the smart grid engineering process can be enhanced. Intervene into the engineering process is possible, and in the following different use cases defined. As listed in Table 1.1, three use cases are analyzed in this scope. Each approach delivers an enhanced smart grid engineering support system from different perspectives.

Table 1.1.: Requirements and Use Cases

Use Case	Requirement	ID
User driven support system	– Self improving software based on new user experiences	A1
	– Customized recommendations for current engineering step	A2
	– Human machine interface for recommendations	A3
	– Facilitated engineering for user	A4
	– No influence on the user-friendliness (measured on software speed)	A5
Error avoidance system	– Domain specific knowledge representation	B1
	– Exclusion process	B2
	– Alerts for fault detection	B3
	– Background verification	B4
	– No influence on the user-friendliness (measured on software speed)	B5
Domain driven support system	– On the specific implementation adapting domain information	C1
	– Recommendations based on domain specific information	C2
	– Human machine interface for recommendations	C3
	– Facilitated engineering for user	C4
	– No influence on the user-friendliness (measured on software speed)	C5

A User driven Support System, with its main aim to reduce the effort by facilitating the engineering process for a user, is one listed use case. This requires a self improving software based on new user experiences and a resulting individual information based human machine interface. In this use case the software evolves with the user, which can be, as an example, the focal points of a company or research institution. As a further use case, the error avoidance system, in a supporting manner, requires a background verification during the whole engineering process, whereby alerts for fault detection are needed. Thereby the user utilizes domain specific knowledge or an exclusion process algorithm, which has to be defined. Considering also a domain driven engineering process approach into one use case, on several steps the user is confrontation with a large magnitude of domain specific content. For obtaining supporting recommendations based on these specific content, a human machine interface is needed, as well as a background process which prepares the data in advance. All use cases require that these algorithms have no influence on the software speed and facilitate the smart grid engineering by reducing the work effort. Hereby the reference to Nah (2004), who points out that "*0.1 second is about the limit for having the user feel that the system is reacting instantaneously*", defines the required performance time.

1.3. Structure of the Thesis

Based on "What Makes Good Research in Software Engineering?" by Shaw (2002), where research strategies are introduced and scoped in question, result and validation (see Table 1.2), this thesis addresses the type of question "Feasibility" by investigating the enhancement of the smart grid engineering process. Therefore, the state of the art of the engineering process as well as different artificial intelligence techniques will be considered in Chapter 2 firstly, to be able to introduce concepts for an artificial intelligence based enhanced smart grid engineering system in Chapter 3. After a comparison between these concepts based on the consideration "The feasibility to adapt this artificial intelligence technique to the smart grid domain", the concept, which needs to be investigate in a much more comprehensive manner to be able to conclude its technical practicability, will be selected. The resulting and descriptive model will be evaluated in Chapter 4 "Proof of Concept Evaluation" and concluding discussed in regard to the requirements from Table 1.1.

Table 1.2.: Research questions in software engineering by Shaw (2002)

Type of question	Examples
Method or means of development	– How can we do/create (or automate doing) X? – What is a better way to do/create X?
Method for analysis	– How can I evaluate the quality/correctness of X? – How do I choose between X and Y?
Design, evaluation, or analysis of a particular instance	– What is a (better) design or implementation for application X? – What is property X of artifact/method Y? – How does X compare to Y? – What is the current state of X / practice of Y?
Generalization or characterization	– Given X, what will Y (necessarily) be? – What, exactly, do we mean by X? – What are the important characteristics of X? – What is a good formal/empirical model for X? – What are the varieties of X, how are they related?
Feasibility	– Does X even exist, and if so what is it like? – Is it possible to accomplish X at all?

2. State of the Art

Enhancing the smart grid engineering process as the core of this work requires a substantially scope on the current process characteristics to be able to discuss methods which are suitable to improve the engineering processes by identifying critical steps in the next chapters. With the, in this chapter introduced state of the art of artificial intelligence techniques and itselfs branch machine learning, such methods are outlined. Additionally a reference to the Austrian project "Model-based Engineering and Validation Support for Cyber-Physical Energy Systems (MESSE)" (Pröstl-Andrén et al. (2018)) implies current achievements in this field.

2.1. Engineering Process in the Smart Grid Domain

The overall engineering process can be separated into three phases, starting with the sub-process specification, where use cases, requirements and stakeholders are defined, the engineering process continues with the Engineering and proceeds with validation and deployment, which covers the Factory Acceptance Test (FAT) and Site Acceptance Test (SAT) (see Figure 2.1). Before the operation phase starts, the outcome of each phase influences the whole engineering process, whereby all sub-process require a reconfigurable and flexible methodology. In this scope, the main focus is based on the specification and use case design.

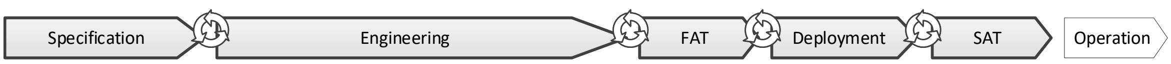


Figure 2.1.: Smart grid engineering process based on Pröstl-Andrén et al. (2018)

2.1.1. Specification and Use Case Design

As outlined in Chapter 1.1, the different actors, stakeholders and components from different domains increases the complexity of smart grid use cases, due to the upcomming interoperability challenges or new businessmodels. To handle these complex use cases in power systems, two models are common in the smart grid domain to identify and specify these approaches as well as in their information and communication exchange. The so called Smart Grid Architecture Model (SGAM) by European Commission (EC) M/490 (2012) on the one hand, and the IntelliGrid Methodology for Developing Requirements for Energy Systems (IEC 62559) by the International Electrotechnical Commission (2015) on the other hand provide a comprehensive and compact overview, while defining the specification and use case design.

Smart Grid Architecture Model

SGAM in its underlying core was to scope standardization activities in the smart grid domain (European Commission (EC) M/490 (2012)), whereby the development of SGAM led to an established tool in industry and research with an application feasibility, which is as well adaptable to larger use cases (see Trefke et al. (2013)). Moreover, the so called "SGAM Toolbox" as a domain specific model language for modelling SGAM exist Neureiter (2017). The architecture concept of SGAM is illustrated in 2.2.

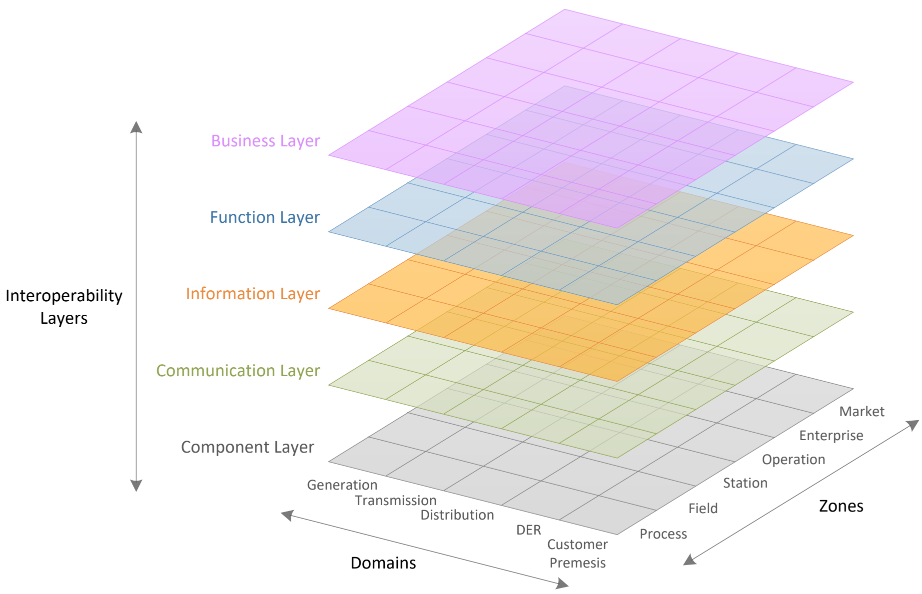


Figure 2.2.: SGAM overview based on European Commission (EC) M/490 (2012)

As represented, this architecture covers a holistic view on smart grid relevant use cases from the component level up to the business level, from generation to the customer and from the market to the process level. Based on Neureiter et al. (2016), the definitions of each layer are listed in Table 2.1.

Table 2.1.: Definition of the SGAM layers based on Neureiter et al. (2016)

Layer	Description
Business	Provides a business view on the information exchange related to smart grids. Regulatory and economic structures can be mapped on this layer
Function	Describes functions and services including their relationships from an architectural viewpoint
Information	Describes information objects being exchanged and the underlying canonical data models
Communication	Describes protocols and mechanisms for the exchange of information between components
Component	Physical distribution of all participating components including power system and ICT equipment

IntelliGrid Methodology and Use Case Template

A further methodology for use case specification is the so called IntelliGrid (IEC 62559). Within this template, an overall use case description is represented. Covering all stakeholders and actors and their physical exchange in a description, the IEC 62559, as partly represented in Figure 2.3 a sequential use case workflow as well as stakeholder analyses are considered in a Unified Modeling Language (UML).

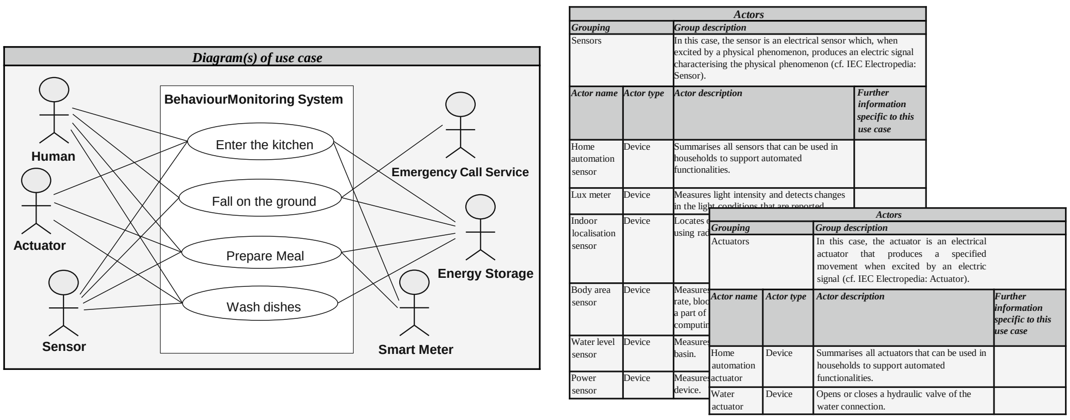


Figure 2.3.: IntelliGrid Use Case template extract from Gottschalk et al. (2017)

Referring to a comprehensive overview, the IntelliGrid Methodology considers the standardization for interoperability issues in the power system domain (in example the definition of security or communication protocols). Hereby the sequential representation of the use case with all actions, stakeholders and their requirements is as well specified.

2.1.2. Engineering

To continue, the second step of the described engineering process is the engineering itself, hereby two general approaches are represented in the literature. With the so called plan-driven methods the engineering process is, as it says, strongly driven by a plan and represented in large and complex projects. Whereby the requirements and results in agile methods dynamically emerge during the process, which is pursued in the modern software engineering (Boehm (2004)). The main differences in the home-ground area are faced in Table 2.2.

Table 2.2.: Home ground for agile and plan-driven methods by Boehm (2002)

Home-ground area	Agile methods	Plan-driven methods
Developers	Agile, knowledgeable, collocated, and collaborative	Plan-oriented; adequate skills; access to external knowledge
Customers	Dedicated, knowledgeable, collocated, collaborative, representative, and empowered	Access to knowledgeable, collaborative, representative, and empowered customers
Requirements	Largely emergent; rapid change	Knowable early; largely stable
Architecture	Designed for current requirements	Designed for current and foreseeable requirements
Refactoring	Inexpensive	Expensive
Size	Smaller teams and products	Larger teams and products
Primary objective	Rapid value	High assurance

2.1.3. Validation and Deployment

As already outlined in Figure 2.1 the Validation and Deployment as the last step of the engineering process, consists of the FAT, the SAT, which represents the Validation, and the Deployment before completing with the Operation. Within the FAT, the overall outcome has to be validated by the developing industry or research institution, whereby the SAT covers the field test with the target environment as the validation environment itself. Widespread validation approaches such as co-simulations, software-in-the-loop and hardware-in-the-loop simulations are represented in the literature (see Ebe et al. (2018)). Furthermore, current projects founded by European Commission such as the European Community's Horizon 2020 Program ERIGrid, pursues an integrated research infrastructure for validating cyber physical energy systems (Otte et al. (2018)).

2.1.4. Model-Based Engineering Support

The Austrian project MESSE addresses these shortcomings with a concept for a model-based engineering and validation support system, covering the overall engineering process for smart grid applications from use case design to validation, and finally deployment and commissioning. Based on a model-driven development approach, the methodology consists of four main parts: (i) specification and use case design, (ii) automated engineering, (iii) validation as well as deployment (see Figure 2.4).

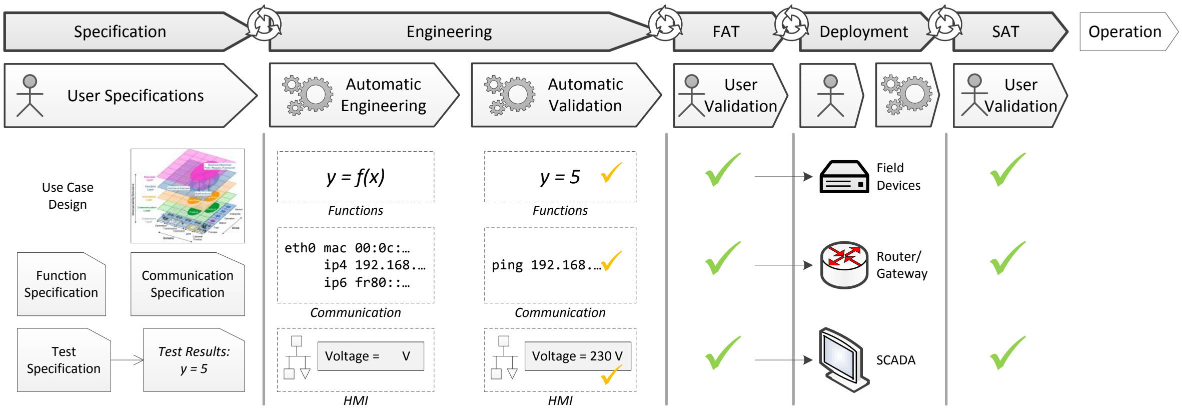


Figure 2.4.: Concept of a model-driven approach for engineering and validation support based on Pröstl-Andrén et al. (2018)

The basis of the method is an automated engineering and validation support to provide further and user specific support during the design. In the dissertation "Model-Driven Engineering for Smart Grid Automation" by Pröstl-Andrén (2018) and "On Fostering SmartGrid Systems Development and Validation with a Model-Based Engineering and Support Framework" by Pröstl-Andrén et al. (2018) this concept is pursued.

2.2. Artificial Intelligence in Power Systems

Identifying suitable methods to enhance the smart grid engineering process requires the investigation of applicable approaches. Considering the current development of artificial intelligence (AI) techniques in power systems and the general achievements of artificial intelligence leads to the investigation of these methods and approaches in the following subsections.

2.2.1. Development and Achievements of Artificial Intelligence

AI at itself is a topic which was first investigate in a psychology and philosophy context by Alan M. Turing (1950). The mathematician Alan Turing is a pioneer in AI and nowadays known for the Turing Machine, the Turing Test and the Turing Award, which is the highest Award in informatics. He introduces the Turing Test for identifying if a machine intelligence is able to act as a human intelligence. Apparently the AI is not a new research field, but has due to the low cost of memory (1957: 411.041.792 $/Mbyte to 2018: 0,0068 $/Mbyte (John C. McCallum (2018))) and the current high performance computing a good fundamental in the nowadays century. A general AI which is able to challenge the natural human intelligence in all areas is missing up to now. However several achievements shows that AI is able to perform as a superhuman intelligence in a specific context. Referring to the theories of the psychologists Howard Gardner (Gardner (2011)) and Louis Leon Thurstone (Thurstone (1938)), the human intelligence respectively primary mental abilities can be divided in types of intelligence (see Table 2.3). An important point to mention is that within the psychological domain no clear definition of the term "Intelligence" exist and on the one hand several approaches pursues the theory behind multiple types of intelligence, whereby on the other hand the idea of a general intelligence exist (see Jensen (1998) and Visser et al. (2006)). However with the theories of Louis Leon Thurstone and Howard Gardner, a comparison of the artificial and human intelligence is more suitable by facing these types with the state of the art of the AI.

Table 2.3.: Types of human intelligence based on the theory of Thurstone (1938)

Primary Mental Abilities	Example	ID
Reasoning	Skills to Reasoning and Deduction	T1
Word fluency	Ability to express language fluently	T2
Verbal comprehension	Skills to understand word-relations and synonyms	T3
Space	Visualization and interpreting the world in three dimensions	T4
Memory	Ability to rely on a fundamental memory with a fast response	T5
Perceptual speed	Understanding object relationships and differences/similarities	T6
Numerical	Handling mathematical problems and ability for calculations	T7

According to the first type of intelligence (T1), chess, as a popular example for deductive and reasoning skills, is frequently associated with a high human intelligence. Therefore, the first popular milestone in AI was reached as the IBM's Deep Blue computer won against the World Chess Champion Garry Kasparov in a six-game match in 1997 (Campbell et al. (2002)). In terms of game complexity, the next milestone was accomplished 19 years later, in 2016 the AI AlphaGo defeats Ke Jie, the world's top Go player. The Game Go is much more complex than chess, with $361!$ $(\approx 14^{767})$ (Chen (2016)), the number of different possible combinations is higher than the number of atoms in the universe. With the introduction of several speech-based natural user interfaces such as home assistants López et al. (2017), the representation of artificial linguistic intelligence, in form of word fluency and verbal relations (T2 and T3), is established and rolled out in the daily basis. In relation to the spatial intelligence (T4) with the three dimensional object detection and orientation, autonomous driving is a major technology with its fundamentals in computer vision and perception (see Geiger et al. (2012)). In order to specify the human abilities, Watzenig and Horn (2016) highlights the statistic from the United States of America, that 2 million vehicle hours, mean time, between fatal crashes and 50 thousand vehicle hours between injury crashes has to be challenged by the autonomous driving and underlines the high requirements in the context of the comparisons between humans and machines. In 2011, the AI called IBM Watson challenges humans in jeopardy, a television gaming show that pursues a contest based on general knowledge answers and the objection is to identify the suitable question (High (2012)) (compare to T5). Extracting an example for the perceptual speed (T6), as a further primary mental ability, with the detection of object similarities a differentiated outline is feasible. Dividing this example into the learning phase on the one hand and the full trained human or rather the machine on the other hand, the learning process of a human kid challenging the identification of objects and relations (i.e. the identification of cats and their relation towards mouses), only a few examples are required for an understanding, whereas the identification of cats based on visual perception is a process for the AI requiring a large set of examples. To conclude with the theory of Thurstone (1938) (T7), calculators are the simplest and most common for demonstrating the fast and reliable calculations based on machines, even if they do not lay down AI approaches. However, raising the complexity of mathematically problems, at the moment, humans are superior than machines, due to the evolving of new mathematically solutions and concepts. In the context of multiple intelligences, Gardner (2011) defends the thesis that interpersonal, intrapersonal and kinesthetical skills are types of intelligence as well. Hence also this ideas are able to face by means of the question "Can computer personalities be human personalities?", Nass et al. (1995) concludes in his work "this research demonstrates that even the most rudimentary manipulations are sufficient to produce powerful effects.". In addition, Kanjo et al. (2018) uses AI for emotion detection. Whereas a reference to kinesthetical abilities, introduced as a further type of multiple intelligences by Gardner (2011), is presented by the research on robotics in surgery (Camarillo et al. (2004)).

General further achievements outline that AI at itself is an interested technique for researchers and industry in wide areas as well as for cultural issues. In example the usage of two neural networks who criticizes each other with the outcome of new art styles Elgammal et al. (2017), and furthermore Roads (1985), Holland (1989) and Miranda (2013) demonstrates that several approaches for the use of AI are able to challenge music approaches. As a final example Catto et al. (2003) presents the bladder cancer prediction, while using AI.

To conclude, even if in all areas several applications exist and as already mentioned an overall AI, which is able to be superior than the human is missing up to now and not even able to fulfill all types (T1-T7) on a basic approach, but what will happen if, for example, an AI is able to manipulate humans, has a much more strength and brings deduction and reasoning to a much more complex level than humans, the usage of AI is not undisputed. Thereby, Stephen Hawking warns that "*artificial intelligence could end mankind*" (Hawking (2014)).

2.2.2. Artificial Intelligence Applications in Power Systems

Besides, how is AI already rolled out in the current power system domain? Considering the Institute of Electrical and Electronics Engineers (IEEE), the IEEE-SA-Standards-Board (2017) defines in the "IEEE Guide for Terms and Concepts in Intelligent Process Automation" Artificial Intelligence as "*The combination of cognitive automation, machine learning, reasoning, hypothesis generation and analysis, natural language processing, and intentional algorithm mutation producing insights and analytics at or above human capability.*". Identifying modern power system applications with a high share of the data science branch AI, a reference towards "Artificial Intelligence Techniques in Power Systems", by Warwick et al. (2008) and "Big Data Application in Power Systems" by Arghandeh and Zhou (2017) outlines various implementations.

In order to clarify the wide area and the potential of AI applications, the approaches starts from power system analysis by N.B.P. Philips and Irving (2008) to alarm analysis by Esp and K.Warwick (2008) over voltage control by A. Ekwue and Macqueen (2008) and an "Expert System Architecture for On-line and Off-line Fault Diagnosis and Control (FDC) of Power-System Equipment" (Jain et al. (2008)). Other topics are considered in protection systems by Aggarwal and Johns (2008), static security assessment by Niebur and Fischl (2008), condition monitoring by J.R. McDonald and Moyes (2008) and demand forecasting by S. Majithia and Hannan (2008). Moreover, Mocanu et al. (2018) point out "*Unprecedented high volumes of data are available in the smart grid context, facilitated by the growth of home energy management systems and advanced metering infrastructure. In order to automatically extract knowledge from, and take advantage of this useful information to improve grid operation, recently developed machine learning techniques can be used*". One further example, applying a machine learning approach on the power system domain, is given by Zehetbauer et al. (2018), where a load profile analysis and characterization via hierarchical clustering is pursued. In Zufferey et al. (2018) unsupervised machine learning shows that useful knowledge of the grid state can be gained without any further information concerning the type of consumer and their habits. Bessa (2018) underlines "*Machine Learning algorithms can be used to control grid assets, for instance embedded in reinforcement learning techniques or to create surrogate models for complex physical systems.*".

2.2.3. Overview of Artificial Intelligence Approaches

To go more into detail, Figure 2.5 outlines the wide research field of AI approaches, whereby the branches itself are highly related to the introduced human mental abilities, which is not unexpected.

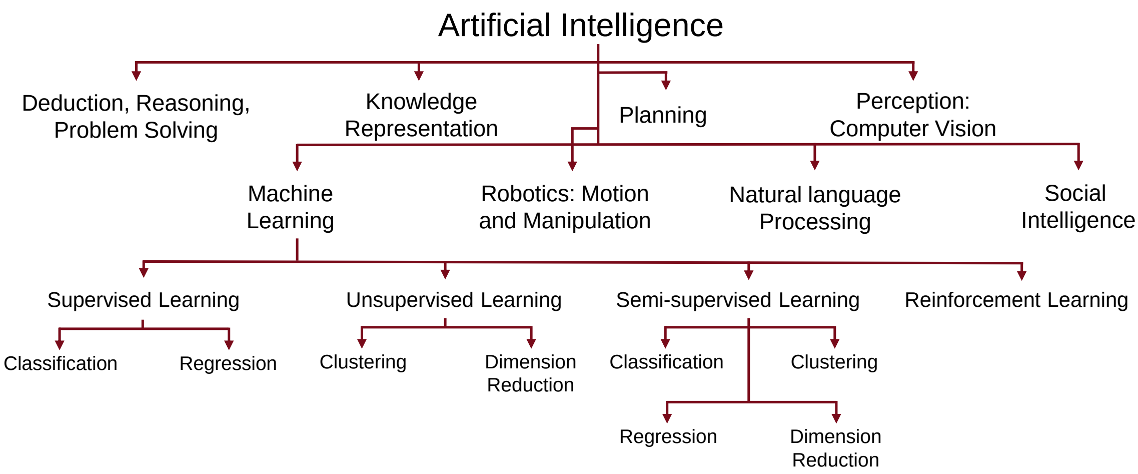


Figure 2.5.: Overview of artificial intelligence based on De Spiegeleire et al. (2017) and enhanced with Louridas and Ebert (2016) and Zhu (2005)

Referring to the first branch, "Deduction, Reasoning, Problem Solving", Bibel (2002) describes reasoning systems as follows: "*Reasoning takes place with a given body of knowledge, say K, already available. In the predictive mode of reasoning we want to determine what facts, say P, could be true in the future. Correct reasoning distinguishes between facts possible on the basis of K, and those which are impossible. In other words, there is a relation which associates K and P in the positive case.*".

Using "Knowledge Representation" also known as expert system or rule based systems as a form of knowledge-based system, in which human knowledge is transferred to a machine readable data set or source code, can be used to adapt domain specific knowledge into an other or related context. As an simple example, the following statement "The grid frequency f decreases, when the demanded power P_{dem} is higher than the generated power P_{gen}, whereby immediately the rotational frequency n of the synchronous generators in the grid decreases as well, while the torque M raises" is basic knowledge in the power system domain but not well known in other fields. Therefore, this term can be transferred to: if $P_{\text{dem}} > P_{\text{gen}} \Rightarrow f \downarrow \Rightarrow n \downarrow, M \uparrow$ as a machine readable expression.

To continue, with "Planning", as the third introduced AI technique in Figure 2.5, the idea of this approach faces the problem on targeting a state (in example a logistic solution for a company). Hereby an "agent" targets this states, while avoiding undesirable states during the process (Boutilier et al. (1999)).

As already outlined in the achievements of AI approaches, "Perception: Computer Vision" is a fundamental part of autonomous driving. With Computer Vision, the detection of objects or persons is feasible for reasoning own interactions based on the environment. A further modern application is augmented reality, which enhances the environment by given advanced information.

Whereas the core of artificial "Social Intelligence" addresses the understanding of interpersonal relations and the detection of emotions. In example, referred to "Emotion recognition based on physiological changes in music listening" by Kim and André (2008) one approach is represented on how social intelligence is implemented.

"Natural language Processing" at itself is commonly used for human machine interfaces, widely spread in home assistants, mobile phones and laptops. The algorithm behind this approach processes the human language with the ability to response to the related topic with an artificial voice.

"Robotics: Motion and Manipulation" addresses the kinesthetical abilities for natural motions of the machine in regard to humans or animals.

"Machine Learning" in general pursues the ability to learn on the basis of a data set, with the outcome to predict, classify, cluster or specify new data with the learned knowledge in form of the trained algorithm.

2.3. Machine Learning - an Artificial Intelligence Approach

Sustaining a comprehensive view on the potently branch of artificial intelligence, machine learning and its different learning approaches will be investigated in the following Section. Referring to the IEEE as well, the IEEE-SA-Standards-Board (2017) defines in the "IEEE Guide for Terms and Concepts in Intelligent Process Automation" the Machine Learning term as follows "*Detection, correlation, and pattern recognition generated through machine-based observation of human operation of software systems along with ongoing self-informing regression algorithms for machine-based determination of successful operation leading to useful predictive analytics or prescriptive analytics capability.*". Consequently, the integration of machine learning into the electrical domain is positively assessed.

Within machine learning, various learning approaches are represented in literature. In the scope of this work four machine learning methods (supervised, unsupervised, semi-supervised and reinforcement learning, see Figure 2.6) are outlined and described in relation to an example. To go more into detail, each learning technique lies down a multitude of mathematical approaches, whereby the complexity as well as the circumferences increase. Referring to the purpose of this work, this section gives an outline of the general principles to be able to apply these learning techniques on the later discussed concepts.

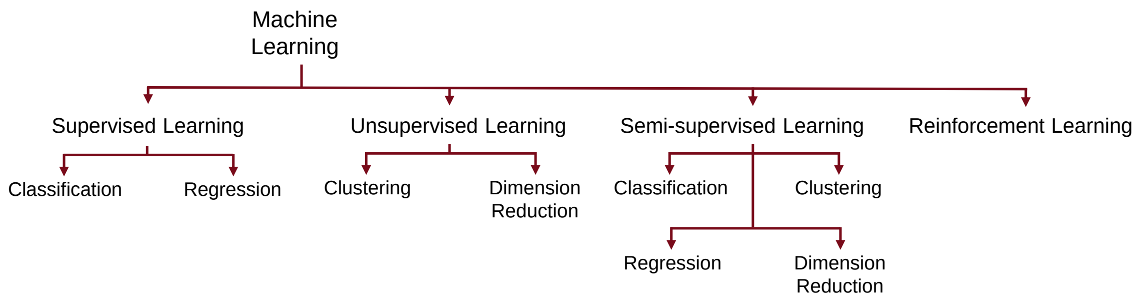


Figure 2.6.: Overview of machine learning based on De Spiegeleire et al. (2017) and enhanced with Louridas and Ebert (2016) and Zhu (2005)

2.3.1. Supervised Learning

Applying a supervised learning method on a data driven problem, where the data structure is represented with the input parameters and their correct output results, the supervised machine learning approach learns how to identify the behaviour between the correct output and the input. For training this machine learning technique, a data set is required as a learning set for the algorithm to improve these abilities. Hereby, the trained algorithm is able to detect the correct output based on new unknown and unlabeled data sets. In addition to that, the fundamental concept of classification, as one supervised machine learning method, is illustrated in the following Figure.

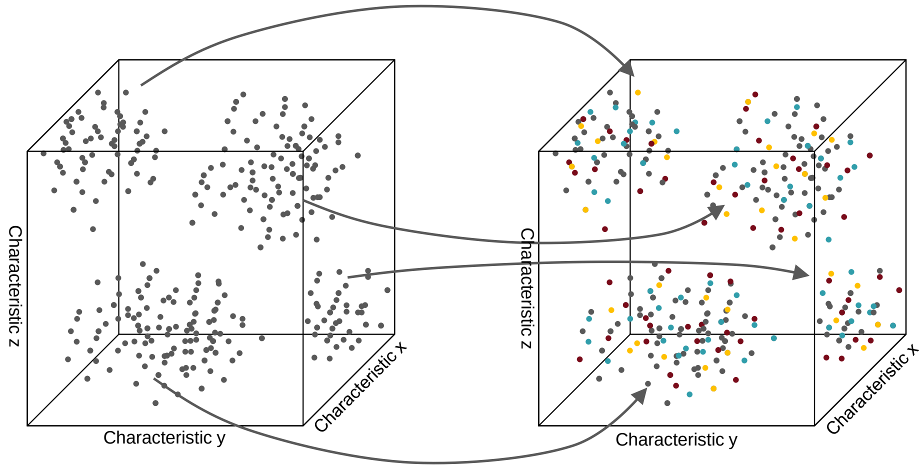


Figure 2.7.: Supervised machine learning classifies the datapoints in the left cube by the characteristics x, y and z

Hereby, the trained algorithm is able to classify the datapoints in the cubes. As an further practically example, for real measurements of an renewable wind power plant, the trained algorithm is capable to classify these values. Besides classification, Louridas and Ebert (2016) differing describes regression as the second branch of the supervised learning, whereat, classification applications are based on logic regression, classification trees, support vector machines and random forests, the regression, which includes linear regression, decision trees, Bayesian networks and fuzzy classification, is described as "*a wider sense than merely statistical regression*".

2.3.2. Unsupervised Learning

A further machine learning approach is based on unsupervised learning, in which the algorithm is trained without labeled data, which is the main difference in comparison to the supervised learning. Investigating this learning approach, unsupervised machine learning algorithms identify structures and patterns in the data, whereby within this learning method hidden information and solutions can be extracted from the data to gain further knowledge. In Figure 2.8, two three dimensional spaces are illustrated with data points, which are comparable by its characteristics (x, y and z).

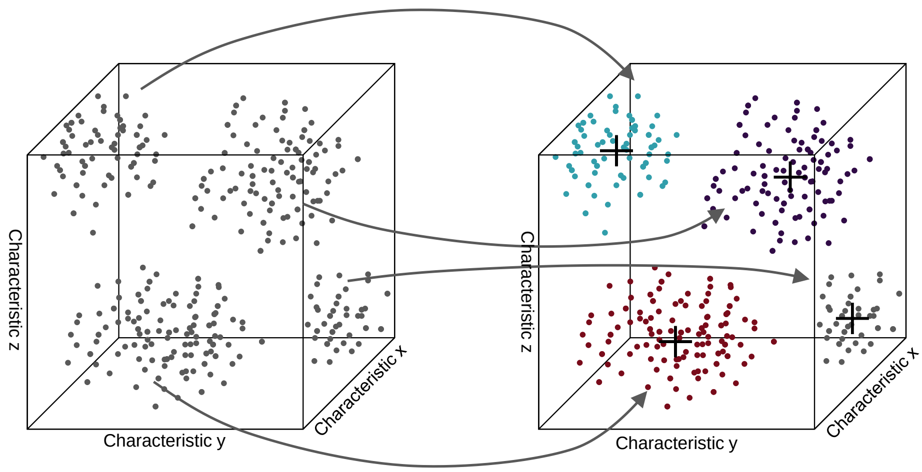
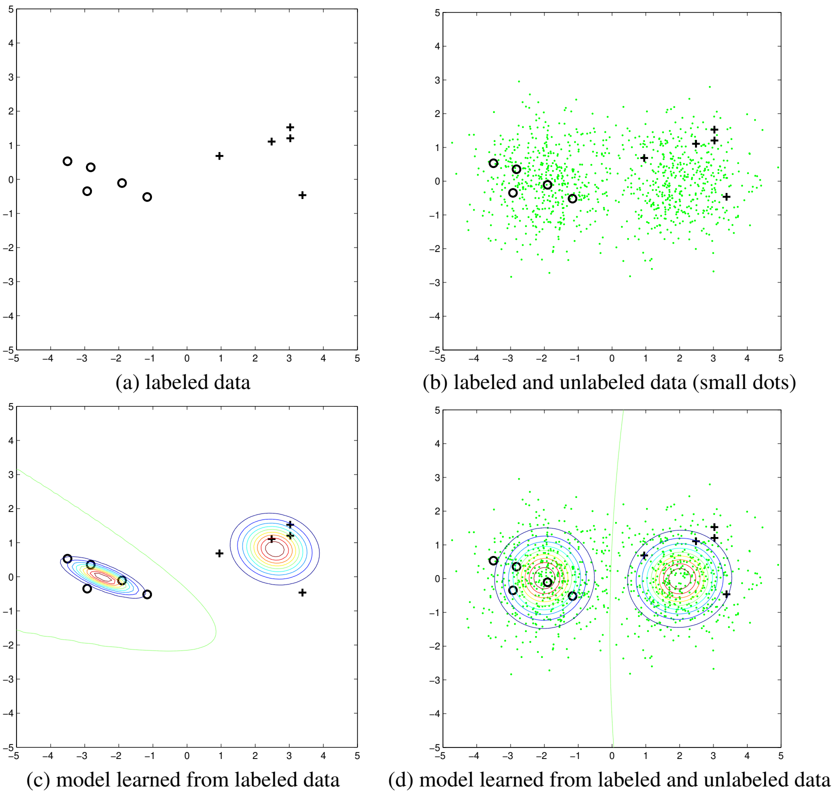


Figure 2.8.: Unsupervised machine learning clustering approach identifies structures and pattern in the left dataset by the characteristics x, y and z with their cores represented as $+$

Applying an unsupervised machine learning method on this problem, within these spaces pattern or structures will be able to detect by this method, i.e., in form of cluster as a result of the so called clustering (k-means, hierarchical clustering, Gaussian mixture models and genetic algorithms). Referring to Louridas and Ebert (2016) , within the scope of unsupervised learning, the dimensionality reduction (component analysis, tensor reduction, multidimensional statistics, random projection) is the second branch.

2.3.3. Semi-supervised Learning

Including the advantages of a supervised and unsupervised learning, the semi-supervised learning contains unlabeled and labeled data as well to extract more information within the set. The main reason is that the integration of classification and clustering obtains a more comprehensive information content. Figure 2.9 contrasts the result of a labeled data set ((a) and (c)) with the by unlabeled data enhanced set ((b) and (d)).



(a) labeled data
(b) labeled and unlabeled data (small dots)
(c) model learned from labeled data
(d) model learned from labeled and unlabeled data

Figure 2.9.: Supervised dataset (a) with the outcome in (c) compared to semi-supervised clustering (d) based on labeled and unlabeled data (b) (Zhu (2005))

Consequently, the quality of the result is higher due to a more preciser cluster model. The development of such a machine learning approach is driven by a large effort in the context of supervised learning, where the labeling of data set is required and often done by humans Zhu (2011).

2.3.4. Reinforcement learning

Kaelbling et al. (1996) describe reinforcement learning as follows "*Reinforcement learning is the problem faced by an agent that must learn behavior through trial-and-error interactions with a dynamic environment*". The authors highlight two main strategies for solving reinforcement learning strategies. One is defined as "*to search in the space of behaviors in order to find one that performs well in the environment*". Whereas the second approach has its fundamental in "*statistical techniques and dynamic programming methods to estimate the utility of taking actions in states of the world*". One example of such an approach is commonly realized based on an artificial neural network, where the underlying core is illustrated in Figure 2.10.

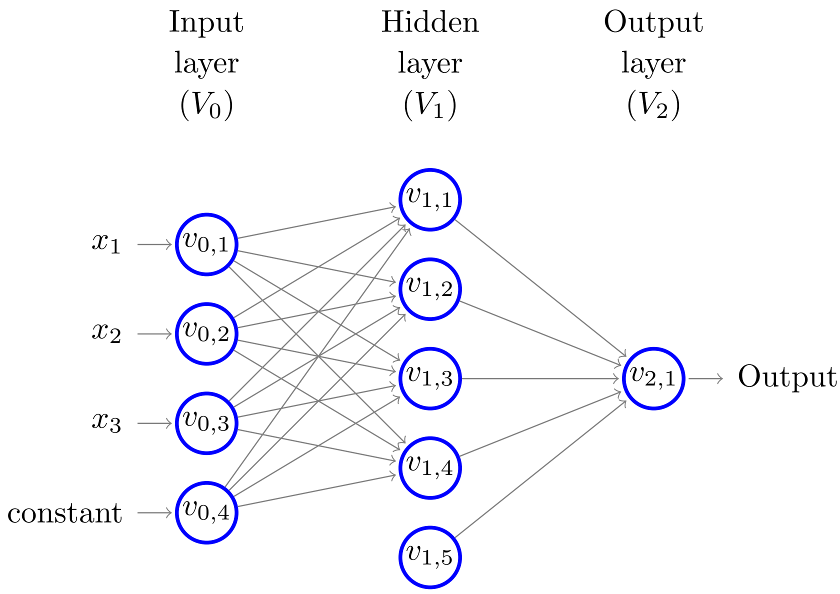


Figure 2.10.: The concept of an Artificial Neural Network based Reinforcement machine learning approach with its layers (V_0, V_1, V_2) based on Shalev-Shwartz and Ben-David (2014)

Shalev-Shwartz and Ben-David (2014) defines "*The idea behind neural networks is that many neurons can be joined together by communication links to carry out complex computations*", the representation in Figure 2.10 is the simplified theory, which separate the network into different layers of connected neurons. With the input layer, hidden layers and the output of the Artificial Neural Network (ANN), the training process to improve by evaluating the values and connections of the neurons, is backwards, whereas the calculation of the output lays down the input values of the input layer.

3. Concept for an Enhanced Smart Grid Engineering

Reflecting the steps of the engineering process through facing it with possibilities of AI techniques, different ideas on how the smart grid engineering process can be enhanced emerges, which are described and compared in the following sections. Evolving these concepts, the feasibility will be evaluated on the technical point of view, hereby assumption are made, which concepts are able to realize with no further investigations and which needs to be evaluated in a much more comprehensive manner.

3.1. Potential Application Approaches for Smart Grid Support Systems

As outlined in Section 2.1.4, the Austrian MESSE project covers the engineering process with automated engineering and validation support, whereby the support based on a cognitive learning approach is one further goal as well.

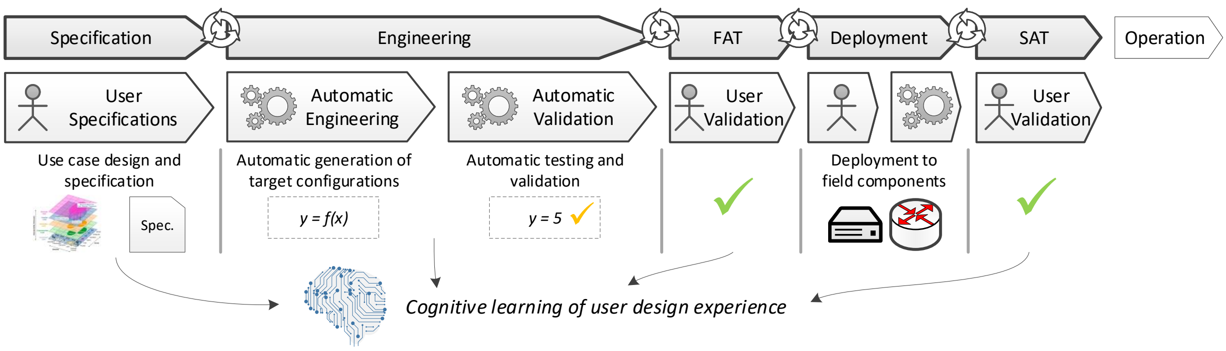


Figure 3.1.: Concept of a model-driven approach for engineering and validation support with a cognitive learning approach based on the Austrian MESSE project

Hereby the definition of cognitive by the IEEE-SA-Standards-Board (2017) refers to machine learning and is as follows "*The identification, assessment, and application of available machine learning algorithms for the purpose of leveraging domain knowledge and reasoning to further automate the machine learning already present in a manner that may be thought of as cognitive. With cognitive automation, the system performs corrective actions driven by knowledge of the underlying analytics tool itself, iterates its own automation approaches and algorithms for more expansive or more thorough analysis, and is thereby able to fulfill its purpose. The automation of the cognitive process refines itself and dynamically generates novel hypotheses that it can likewise assess against its existing corpus and other information resources.*". In Figure 3.1 the overall concept captures the engineering process as a process, where each step can be improved and supported by cognitive intelligence. Therefore, different concepts based on "cognitive learning of user design experience" are feasible and elaborated in the next sections.

3.2. Overall Concept

Within this section, three concepts are introduced for enhancing the smart grid engineering process by using machine learning and further AI techniques. Considering the large amount of engineering process work flow approaches on each step, in the scope of these concepts, the enhancements are point on the transition between the use case specification and the engineering. To outline each concept, one visual-based mock-up is illustrated in each subsection, whereby the concepts can be compared and analyzed. Additionally, solutions based on textual processing are feasible as well in the context of automated engineering and validation support but compared to possible User Interfaces less clearer to express the functionality in an outline. Therefore, mock-up representations, listed in Figures 3.2, 3.3 and 3.4 of this section, are structured equal, with the component layer of the SGAM, which was described in Section 2.1.1 and commonly used for use case design, as the core of the representation. The left areas purposes a demonstration and overview with the opportunity to choose components based on the domain and zone areas of SGAM. Besides, the more important content is the AI, which adapts the following concepts and supports the user in the right area of the mock-up representation.

3.2.1. Error Avoiding Expert System

Reducing the work effort and avoiding failures at the same time, an expert system successfully challenges fault diagnosis issues in power systems Jain et al. (2008), but it can be used to include fundamental background from the electrical domain or the Information and Communication Technology (ICT) at the same time to cover the aspect on effort reduction as well. Considering related topics as well, Zhang et al. (1989) surveys the usage in different applications of engineering, which underlines the potential of this artificial intelligence branch in power systems. In general, a holistic use case specification has the best preconditions for further engineering steps, however a holistic view is also affiliated to a large amount of several domain specific knowledge. Therefore, this expert system challenges this problem by representing the human engineering knowledge into a machine implementable information set. In Figure 3.2 the possible concept is illustrated.

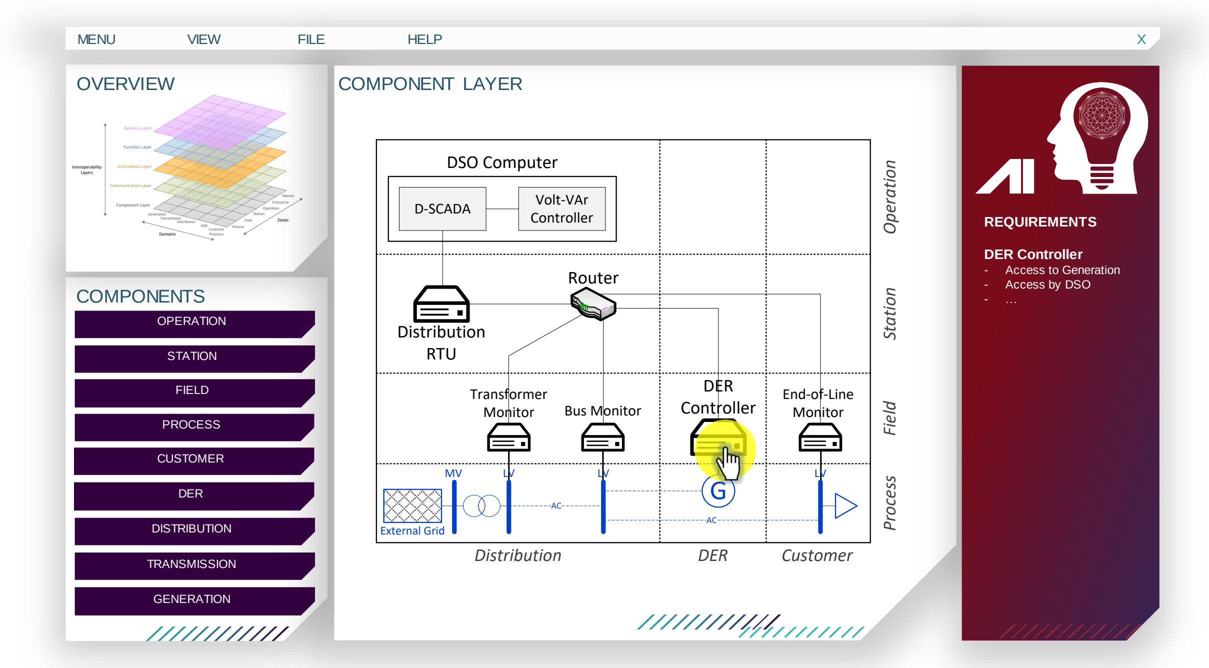


Figure 3.2.: Mock-up: Possible application for an error avoiding support system based on expert systems

With this expert system, the engineer is supported by requirements, which are related to the use case specification to fulfill a holistic use case specification for the further steps of the engineering process.

3.2.2. Artificial Neural Network-based User Supporting System

ANN-based learning approaches are a common method for adapting user experiences and behaviors. In "Deep Neural Networks for YouTube Recommendations" Covington et al. (2016), such an approach is represented for a large scale user-driven software solution. Transferring an equivalent solution to the smart grid domain, could be used to obtain a machine learning supporting system, which is represented in Figure 3.3 in a visual-based mock-up.

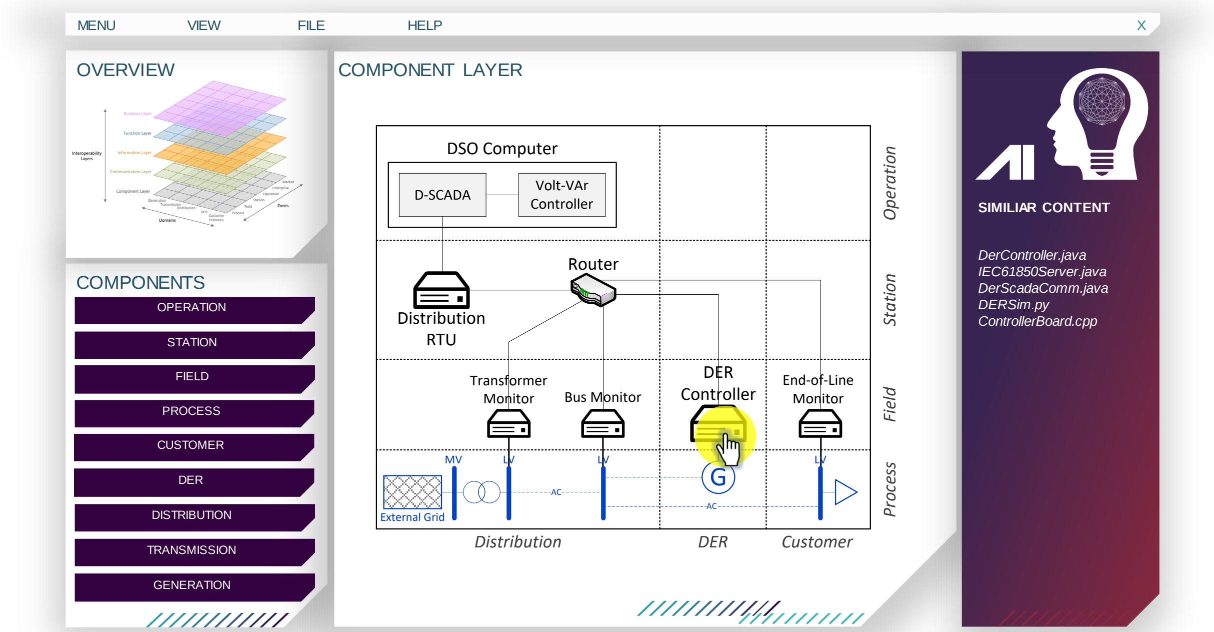


Figure 3.3.: Mock-up: Possible application for an ANN-based support system based on user design experiences (recommendations on the right)

As outlined, the mock-up which provides recommendations related to similar content of previous implementations or projects. Hereby the artificial intelligence recommends different implementation approaches and files. Such an solution addresses larger companies or research institutions, in which a larger data set of projects exist and the behaviour can be applied on a neural network approach due to a highly used specification software.

3.2.3. Clustering Approach for a Domain driven Support System

Regarding to the description in Section 2.1.1, where standardization at itself is very common in the specification and use case design due to the required information in the SGAM as well as in the IntelliGrid methodology (IEC 62559). However, the smart grid domain includes hundreds of standardization approaches and the entrenched "Smart Grid Standards Map" by International Electrotechnical Commission (a), which delivers a good overview for standards on the one hand, but on the other hand, the identification of related standards is time consuming for larger use cases. As summarized in Section 2.3, clustering, as a machine learning method, is able to identify hidden structures in data sets. Covering these standardization approaches as a data set with the unsupervised, supervised or semi-supervised machine learning method, the identification of structures or classifications are usable for recommendations of applicably standards for the use case. To underline the needs of recommendations in standardization, Rohjans et al. (2010) point out nine different recommendation approaches for the smart grid domain, whereby the need of recommendations becomes clearly. To take up this point, in Figure 3.4 a possible application is represented, that, based on the defined use case, is able to recommend suitable standards and gives an outlook, which standards might be relevant in a wider sense as well.

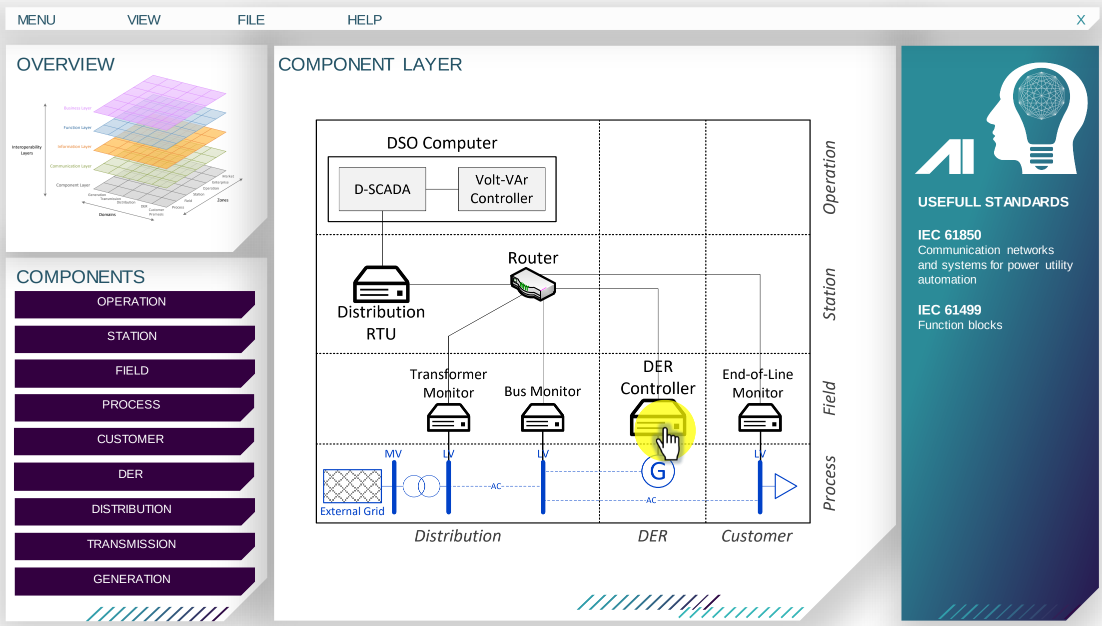


Figure 3.4.: Mock-up: Possible application for a domain driven support system based on clustering different standards (recommendations on the right)

3.3. Selected Concept

With the prospects on the feasibility of the introduced use cases, in this section the state of the art will be considered, to select the number of use cases which are able to be realized from the technical point of view and which needs to be investigate in a more comprehensive manner.

Related to the state of the art in Chapter 2, the usage of neural networks for recommendations based on user experiences, similar content or habits is already successfully used in different domains. Hereby, a proof of concept of the user driven support system (see Table 1.1) will not be further investigated with the adoption that this use case is able to apply on the smart grid engineering process. Regarding to the second use case, which is defined in Table 1.1, the introduced error avoidance system concept based on an expert system is similar represented in the survey of Zhang et al. (1989) as a "Prescription" and further applications for related power system fields are listed. Additionally, referring to the given example in Section 2.2.3, much more simplified knowledge can be incorporated. Therefore, this use case could also be adapted to an enhanced smart grid engineering tool with, compared to the other use cases, less effort. Considering all three use cases, the domain driven use case requires domain specific knowledge as well as an domain specific dataset. Therefore, this use case will be prototyped to be able to investigate the feasibility of such a use case.

4. Proof-of-Concept Evaluation

With the outcome concluded in Section 3.3, the concepts which address a user driven supporting system based on neural networks as well as an error avoidance system with an expert system as the core are, with the assertion that these concepts are applicable from the technical point of view, not require a prototypical realization in this scope. However, the outcome shows as well that the investigation of a domain driven supporting system based on machine learning is needed, due to the fact that no similar applications for clustering standards for recommendation issues are represented in the literature. Thereby, a prototypical realization will be pursued in this chapter.

4.1. Selected Validation Example

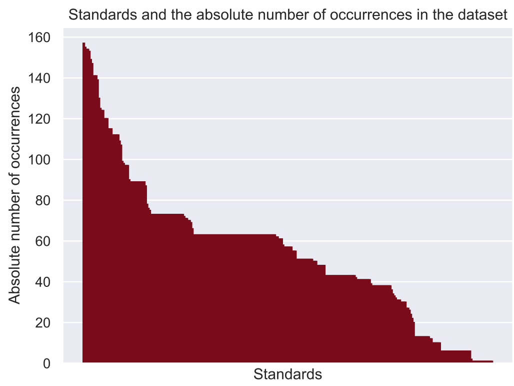
As already referred to in Section 1.3, the introduced research strategies based on "What Makes Good Research in Software Engineering?" by Shaw (2002) advises strategies for the validation as well and suggests the approaches Analysis, Experience, Example, Evaluation and Persuasion. With the realization of a tool prototype, in this scope a validation based on an example is pursued.

4.2. Prototypical Realization

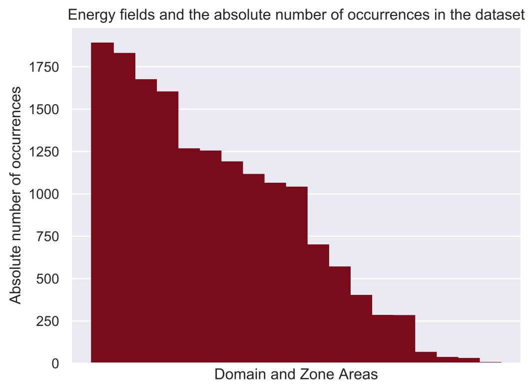
Starting with the explanation, how to validate this prototype, to begin with analyses of the elected dataset and continue with the discussion on which machine learning approach is suitable for this application. Due to this outcome, the method on how to calculate the distance between two standards, to obtain a distance relation between all standards, is represented in Section 4.2.3. With this required step for clustering, in Section 4.2.4 the clustering itself is outlined. After presenting the search algorithm, the theoretical approaches concludes with the tool prototype itself and the results and discussion. Developing a domain driven supporting system based on standards requires a dataset which contains characteristics of the standards itself. In advance it is necessary to analyze the dataset, to be able to validate the result and choose the best suitable machine learning method.

4.2.1. Investigation of the Smart Grid Standardization Data Set

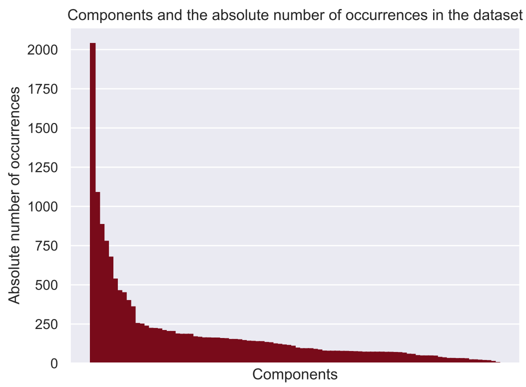
In this scope, 298 standards and guidelines from the Smart Grid Standards Map based on International Electrotechnical Commission (a) and International Telecommunication Union (ITU) are considered. The descriptions are the official specifications of the International Electrotechnical Commission (b) (IEC), whereby all investigated standards and guidelines are appended in Table B.1. The structure of the data set is represented in Figure 4.1d. Within each standard, the domain and zone areas related to the SGAM representation and the components are given. As the Figures 4.1a, 4.1b and 4.1c shows, the absolute number of occurrences in the data structure is not homogeneous, which needs to be considered in the implementation. The overall data consists of 16271 associated datapoints.



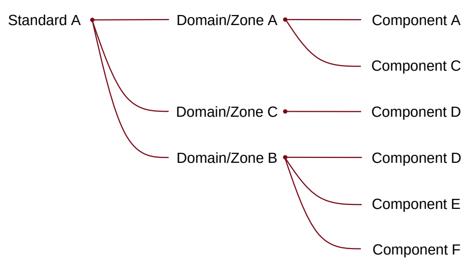
(a) Number of standards



(b) Number of zone and domain areas



(c) Number of components



(d) Structure of the dataset

Figure 4.1.: The absolute number of occurences in the dataset of (a) standards (b) domain and zone areas (c) and the structure of the dataset itself (d)

4.2.2. Selection of a suitable Machine Learning Approach

Concerning all introduced machine learning approaches from Section 2.3, with the gained knowledge of the data characteristics, in this work, an unsupervised machine learning will be pursued. The main cause for this conclusion is the unlabeled data set, which excludes the supervised learning techniques. Indeed, it is possible to label or classify data sets, but applied to these standards in relation to a recommending supporting system, there is no objective way to recommend standards on a given use case. In other words, the user itself, mainly driven by the focus of the company or research institution, has to decide which standards are useful and not the software developer of this supporting system in advance. Thereby, semi-supervised learning approaches are as well not applied on this approach. However, with unsupervised clustering, it is possible to gain a data-structure in the field of standardization for recommending part focuses in form of clusters, to provide a set of standards which are directly useful and which are also recommendable in a wider sense for this use case, to enhance the scope of the user/engineer. As seen in the state of the art, recommendations are often represented on a reinforcement learning basis, but the standards can be seen as a not dynamic data set, since the emerging of new standards is overseeable, whereby the update of this static data is manageable. This leads as well to the advantage that the machine learning algorithm does not require a fast execution, because these unsupervised techniques can be applied to the dataset in advance and only the identification of the clusters within a use case influences the performance of the supporting system.

4.2.3. Calculating the Distance between two Standards

In this subsection three methods for calculating the distance between two standards are described. Using the introduced structure from Figure 4.1d, while considering the inhomogeneous number of occurrences, each standard has to be normalized for a valid comparison. Therefore the number of occurrence of one component, represented as the set A, and all relevant components of the standard, represented as the set B, leads to the valid expression $A \subset B$. Obtaining a normalized weight α_{norm} of each component inside each standard, the cardinality (represented here as $\#$) will be used to divide the cardinality of A with the cardinality of B (see equation 4.1).

$$\alpha_{\text{norm}} = \frac{\#A}{\#B} \tag{4.1}$$

Calculating now the distance between two standards, each standard is represented with a vector containing the α_{norm} of each component, hereby α_{norm} is equals 1 when one component represents the whole standard and 0 when this component is not part of the standard.

In the following methods the vector $\vec{x}$ represents standard X and $\vec{y}$ contains all α_{norm} values of standard Y.

M1: Calculating the distance based on components

The simplest introduced equation on calculation the distance is based on the cardinality of the components inside a standard. Defining all components and their cardinality of one standard in a vector is represented in $\vec{x}$ where $x_{\text{i}} = \alpha_{\text{norm}}$ of each component. The equation 4.2 calculates the the similarity between the vectors of two standards ($\vec{x}$ and $\vec{y}$).

$$\delta_{\text{Stand, 1}}(\vec{x}, \vec{y}) = \frac{\sum_{i=0}^{N} x_{\text{i}} \cdot y_{\text{i}}}{max(\sum_{i=0}^{N} {x_{\text{i}}}^2, \sum_{i=0}^{N} {y_{\text{i}}}^2)} \tag{4.2}$$

With $0 \leq \delta_{\text{Stand, 1}} \leq 1$ a value represents the distance between two standards, where zero is defined as the minimum of similarity (no similarity) and one is defined as 'equal'. An important fact, the multiplication in the numerator implies that with the specific normalized weight α_{norm} of one component related to the standard (i.e. x_{i}) compared to the other specific value (y_{i}) is zero, if one component has no influence in the standard. With the term in the denominator the distance $\delta_{\text{Stand, 1}}(\vec{x}, \vec{y})$ is normalized.

M2: Calculating the distance based on components, domain and zone areas

The second approach for calculating the similarity δ_{Stand} includes also the information about the domain and zone areas in which the standard is used. Considering the impact of the inhomogeneous representation of each domain and zone area in the data structure as well, the calculation for the normalized weight α_{norm} has to be adopted for this method. Hereby the new vectors $\vec{v}$ and $\vec{w}$ are introduced, which contains the weights of each domain and zone area. Pointing out the term domain and zone areas, the component layer of the SGAM in the previous Figure 2.2 clarifies these areas. In equation 4.3, the calculation 4.2 is enhanced by the weighted values of the areas on the same approach as in 4.2 and divided by 2 to obtain a distance in the range $0 \leq \delta_{\text{Stand, 2}} \leq 1$ as well.

$$\delta_{\text{Stand, 2}}(\vec{v}, \vec{w}, \vec{x}, \vec{y}) = \frac{1}{2} \cdot \left(\frac{\sum_{i=0}^{N} v_{\text{i}} \cdot w_{\text{i}}}{max(\sum_{i=0}^{N} {v_{\text{i}}}^2, \sum_{i=0}^{N} {w_{\text{i}}}^2)} + \delta_{\text{Stand, 1}}(\vec{x}, \vec{y}) \right) \tag{4.3}$$

M3: Calculating the distance based on components, domain and zone distances

Representing a method, which consider the introduced weighted values of the vectors $\vec{v}$ and $\vec{w}$ as well as a domain specific application method, a coupling between the introduced weighted values and a coupling between the domain and zone areas is pursued in the third method. Within this method it is supposed, that the domain and zone areas have a distance in comparison to the other areas as well. For this calculating the distance $\delta_{\text{D, Z Areas}}(A, B)$, two new matrices are introduced, which presents an arbitrary layer of the SGAM approach (see Figure 2.2).

$$\delta_{\text{D, Z Areas}}(A, B) = \sum_{i=0}^{G} \sum_{j=0}^{H} \frac{|A_{\text{ij}} - B_{\text{ij}}|}{A_{\text{ij}} + B_{\text{ij}}} \tag{4.4}$$

With A and B as the heat matrix for the domain and zone area and $0 \leq \delta_{\text{D, Z Areas}} \leq 1$, with $\delta_{\text{D, Z Areas}} = 1$ means highest similarity. The $\delta_{\text{Stand, 3}}$ is calculated as follows:

$$\theta(\vec{v}, \vec{w}) = \sum_{i=0}^{M} \sum_{j=0}^{N} v_{\text{i}} \cdot w_{\text{j}} \cdot \delta_{\text{D, Z Areas}}(A_{\text{v}_{\text{i}}}, B_{\text{w}_{\text{j}}}) \tag{4.5}$$

$$\delta_{\text{Stand, 3}}(\vec{v}, \vec{w}, \vec{x}, \vec{y}) = \theta_{\text{norm}}(\vec{v}, \vec{w}) \cdot \delta_{\text{Stand, 1}}(\vec{x}, \vec{y}) \quad \text{with } \theta_{\text{norm}} = \frac{\theta_{\text{ij}}(\vec{v}, \vec{w})}{max(\theta_{\text{i}})} \tag{4.6}$$

Overview of the three standard distances

Obtaining an overview of the three methods, the representation of similarities in form of distances between comparable data points is common in a so called heatmap. In Figure 4.2, the resulting similarity δ_{Stand} of all approaches are illustrated. The axis of abscissas and the axis of ordinates as well list all investigated 298 standards. As represented in the color bar on the right, dark colors indicate a low use case intersection, whereas bright colors highlights a high intersection. With the same sorted matrix elements, the methods are comparable. Hence, the diagonal line in the matrices shows that the all methods are valid, due to the fact that this axis is indicated with a white color ($\delta_{\text{Stand}} = 1 = max$) and illustrates the axial symmetry. While considering special areas within all heatmaps, the outcome shows that all methods identify related similarities but with different δ_{Stand}. A further interesting fact is extractable from the heatmap of method 3, even if both methods (M1 and M2) outline a higher similarity, through the coupling between the zone and domain areas, a lower similarity is gained. To sum up, all three methods have different focal points and it has to be considered that with all methods an overall evaluation is not striven, which points out that one approach

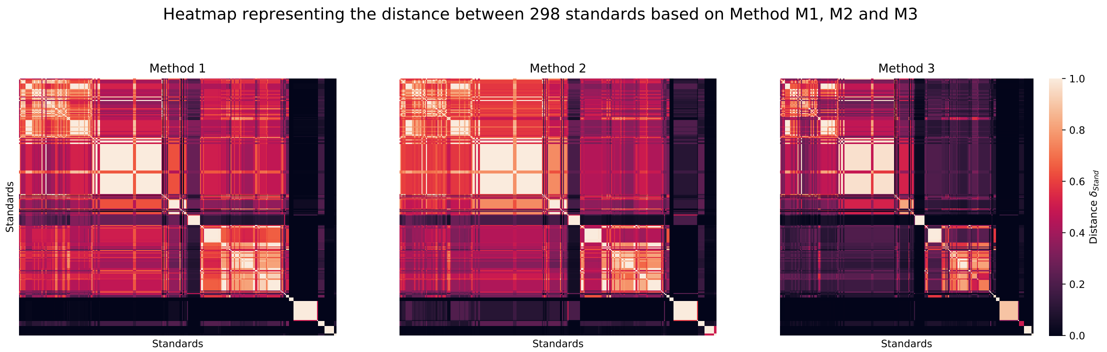


Figure 4.2.: Heatmap representation for the comparison results of the three methods
1 → 100% distance similarity - 0 → 0% distance similarity

is better than the other. It has taken in to account that these method may address different applications.

4.2.4. Clustering Approach for Standards

As outlined in Section 3.2.3, different clustering approaches are represented in the literature based on unsupervised and semi-supervised machine learning. Referring to the outlined advantages regarding to hierarchical clustering by Zschunke (2003), the flexible cluster size in hierarchical clustering contributes more degrees of freedom, which is in fact useful for the number of recommended standards in the targeted domain driven supporting system. Moreover, Shalizi (2009) criticizes that an optimal size or number for clusters is not clearly defined and bases his argument with the example that in extreme, each datapoint shell be one cluster to obtain the most perfect size based on the most significance information content, but it has a pointless result, since no new outcome is gained. In the opposite, larger clusters are able to represent new structures but the similarity within these clusters creases the quality. However, several approaches for identifying the optimum sizes like the Elbow-method (see Bholowalia and Kumar (2014)) or Gap-method (see Tibshirani et al. (2001)) are commonly accepted in literature and identifies balances between these extremes. Adapting these arguments on the desired concept, both cluster size approaches are feasible, but the flexibility delivers a more comprehensive outcome. Within hierarchical clustering several linkage methods exist and Murtagh (1983) discusses six methods (Single link (nearest neighbour), Complete link (diameter), Group average (average link, UPGMA), Median (Gower's method, WPGMC), Centroid (UPGMC) and Ward's method (minimum variance, error sum of squares)) and clarifies in regard to Ward's method: "*the reducibility property ensures that the resulting hierarchy is unique and exact*". Therefore this linkage method is pursued in the further investigated steps.

Hierarchical Clustering based on Wards Method

Based on Shalizi (2009), "*the Ward's method says that the distance between two clusters, A and B, is how much the sum of squares will increase when we merge them:*

$$\Delta(A, B) = \sum_{i \in A \cup B} ||\vec{x}_i - \vec{m}_{A \cup B}||^2 - \sum_{i \in A} ||\vec{x}_i - \vec{m}_A||^2 - \sum_{i \in B} ||\vec{x}_i - \vec{m}_B||^2 \quad (4.7)$$

$$\Delta(A, B) = \frac{n_A \cdot n_B}{n_A + n_B} ||\vec{m}_A - \vec{m}_B||^2 \quad (4.8)$$

here $\vec{m}_j$ is the center of cluster j, and n_j is the number of points in it. Δ is called the merging cost of combining the clusters A and B". To reduce the work, within the python library SciPy, an implemented linkage method based on the wards method is already provided. Visualizing the hierarchical clustering result, a dendrogram representation outlines these cluster. In Figure 4.3 all three methods are comparable by the dendrogram representations and consists of an shared axis of ordinates, whereby the axis of abscissas lists the standards. An important fact to consider in this Figure is that through the clustering the order of the standards on the x-axis are not the same in all three methods. In general, the dendrogram outlines the cluster in relation to the merging costs Δ. Hence, it it is interpretable how cluster are mergeable.

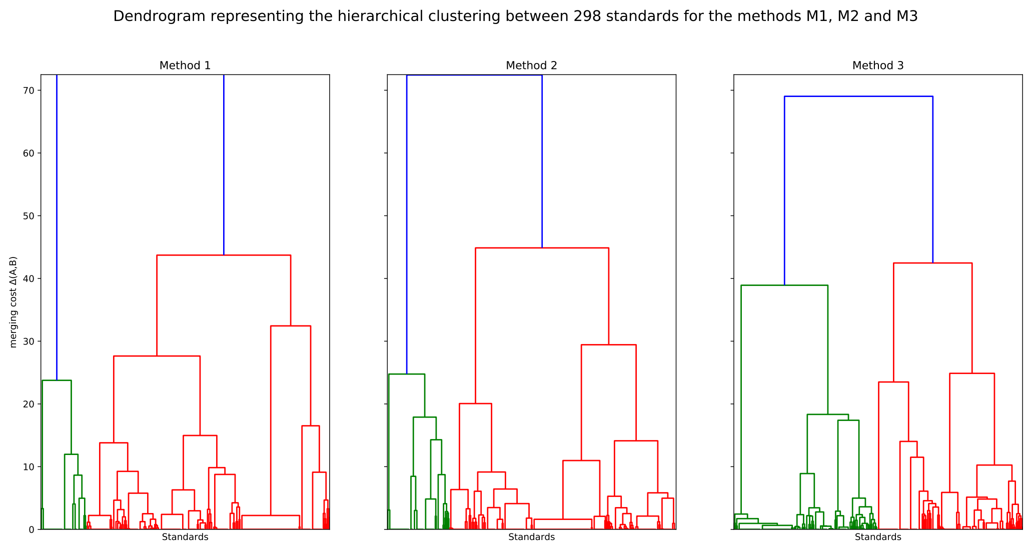


Figure 4.3.: Result of clustering 298 different standards represented in a dendrogram

As outlined, the resulting dendrograms of method 1 and 2 have in general a higher merging cost Δ, when the whole dataset is covered as one cluster. Furthermore, having a closer look on the bottom cluster, with lower merging costs Δ, all three method conclude with a number of 78 cluster and cover similar standard into one cluster.

4.2.5. Search Algorithm for identifying Cluster

Based on the outcome of the hierarchical clustering results, the obtained binary tree structure (see figure 4.3) consists of a number of clusters n, which represents the thematic group of standards. In this subsection two algorithm for the identification of the most suitable recommendation for the use case based on these clusters will be introduced, hereby the number of clusters are defined as n and the maximum number of comparisons as γ_{max}.

S1: Simple Search Algorithm

In this approach, the data structure will be terminated by transferring the lowest leafs of the binary tree into an array. This reduction is feasible due to the symmetry of the tree, but the loss of information are carried along. The simplest search algorithm for an array is given by comparing each characteristic of an element with the characteristics of the investigated element. Hence, the maximum number of comparison is equal to the number of elements within this array n, but also to the minimum number of comparison (see equation 4.9).

$$\gamma_{\text{max, 1}} = \gamma_{\text{min, 1}} = n \tag{4.9}$$

The identified element represents the recommend cluster, whereby the number of recommended cluster can be flexible in regard to the amount of standards or by a given percentage of intersection in comparison to the use case.

S2: Advanced Search Algorithm

In "Clustering algorithms (Overview)" Zschunke (2003) concludes that hierarchical clustering has advantages due to the tree structure representation with no fixed cluster size. Therefore the advanced search algorithm, uses these structures by comparing both leafs of a node with the desired element and chooses the best suitable cluster Hereby the size of each cluster or the number of cluster is flexible as well. Based on Knuth (1997) the maximum number of comparions for this search algorithm would be:

$$\gamma_{\text{max, 2}} = \gamma_{\text{min, 2}} = \log_2(n) + 1 \tag{4.10}$$

This immediately leads to the advantage of a faster performance, which has to be considered related to the introduced requirements.

A further advantage is provided by the mentioned flexibility of this data structure. The termination of the algorithm can be enhanced by considering the desired similarity based on the ward distance (merging costs Δ).

4.2.6. Tool Prototype

Enhanced smart grid engineering with a domain driven support system is outlined in a visual based concept in Section 3.2.3. However the feasibility of this idea is enlargeable by adapting it on an editor based environment. Based on the dissertation of Pröstl-Andrén (2018) a domain specific language is introduced and exist in an Eclipse environment with the framework Xtext (Efftinge and Völter (2006)). The so called Power System Automation Language (PSAL), automatized the design and specification phase to improve the transition to the engineering as the further phase. Underlining this argument, Zanabria et al. (2018) point out as well "PSAL not only supports the development of high-level use case descriptions, it also offers tools for detailed use case specifications". Therefore this environment will be used for validating the domain driven support system. For a tool prototype development based on domain driven data, a clustermodel as a dependency, will be evolved in advance.

Machine learning based Clustermodel

Applying the theoretical unsupervised machine learning approach for clustering smart grid related standards on PSAL, a trained datamodel is required. For the implementation of this clustermodel, Python as the programming language is used. Although PSAL is implemented in JAVA, with Python rapid prototyping is feasible and an exportable clustermodel is implementable as well. Within Python, SciPy provides the implemented Ward's method, which requires the distance matrix as an input parameter, whereby this methodology will be assisted. As mentioned, the methods for calculating the distance δ_{Stand} between two standards (M1, M2, M3) differ in the focus of the considered application, whereby three resulting files exist.

Regarding to an independent data model to represent the outcome of the hierarchical clustering, the tree representation of the model is inherited by an Extensible Markup Language (XML) file. This type of file has the advantage that further implementations based on the introduced supporting system are independent from a programming language specific file and are human readable. In Figure 4.4 an extract in form of one of the 78 clusters is given. Within each cluster, the standards and the components covers the content of these clusters.

With the opening (in example `<Cluster>`) and closing (`</Cluster>`) tags, the tree representation of the dendrogram is reduced to the lowest layer, but extendable to the root node to apply the advanced search algorithm on it. Furthermore, within the `<Components>`, each listed component is unique by its name, whereby the relevance of this component is identifiable.


```
<?xml version="1.0" encoding="ISO-8859-1"?>
<MachineLearningStandardClustering>
 - <Cluster id="41">
   - <Standards>
       <Standard name="IEC 60364-4-41">Low voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock 60364-4-41:2005</Standard>
       <Standard name="IEC 60364-5-53">Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - Isolation, switching and control</Standard>
       <Standard name="IEC 60364-5-55">Electrical installations of buildings - Part 5-55: Selection and erection of electrical equipment - Other equipment</Standard>
       <Standard name="IEC 60364-7-712">Low voltage electrical installations - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems</Standard>
       <Standard name="IEC 60364-7-722">Low-voltage electrical installations - Part 7-722: Requirements for special installations or locations - Supplies for electric vehicles</Standard>
       <Standard name="IEC 60783">Wiring and connectors for electric road vehicles</Standard>
       <Standard name="IEC 60784">Instrumentation for electric road vehicles</Standard>
       <Standard name="IEC 60785">Rotating machines for electric road vehicles</Standard>
       <Standard name="IEC 60786">Controllers for electric road vehicles</Standard>
       <Standard name="IEC 61850-90-8">Communication networks and systems for power utility automation - Part 90-8: Object model for E-mobility</Standard>
       <Standard name="IEC 61851 series">Electric vehicle conductive charging system - Part 1: General requirements</Standard>
       <Standard name="IEC 61851-1">Electric vehicle conductive charging system - Part 1: General requirements</Standard>
       <Standard name="IEC 61851-21">Electric vehicle conductive charging system - Part 21-1 Electric vehicle on-board charger EMC requirements for conductive connection to AC/DC supply</Standard>
       <Standard name="IEC 61851-22">Electric vehicle conductive charging system - Part 22: AC electric vehicle charging station</Standard>
       <Standard name="IEC 61851-23">Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station</Standard>
       <Standard name="IEC 61851-24">Electric vehicle conductive charging system - Part 24: Digital communication between a d.c. EV charging station and an electric vehicle for control of d.c. charging</Standard>
       <Standard name="IEC 61894">Description Not availale at present</Standard>
       <Standard name="IEC 61980 series">Electric vehicle wireless power transfer (WPT) systems - Part 1: General requirements </Standard>
       <Standard name="IEC 61982 series">Secondary batteries (except lithium) for the propulsion of electric road vehicles - Performance and endurance tests</Standard>
       <Standard name="IEC 62196">Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements</Standard>
       <Standard name="ISO 6469">Electrically propelled road vehicles -- Safety specifications </Standard>
       <Standard name="ISO 8713">Electrically propelled road vehicles</Standard>
     </Standards>
   - <Components>
       <Component name="ChargingStation">0.5</Component>
       <Component name="PlugInElectricVehiclesPEV">0.5</Component>
     </Components>
   </Cluster>
</MachineLearningStandardClustering>
```


Figure 4.4.: Extract from XML with model representation of one cluster

Implemented Search Algorithm

In Section 4.2.5 two search algorithms are introduced, which are applicable on extracting the most suitable cluster out of the datastructure. To demonstrate that the simple search algorithm is evaluable by the reuqirements as well, this search approach is pursued. With the evolved XML structure (Figure 4.4), a list, which consists of all cluster as elements, is loadable. As discussed, the XML can be enhanced to a full tree represenation based on the dendrogram to apply the advanced and faster search algorithm on it. The most suitable cluster will be identified on the basis of the use case components in comparison to the overall relevance of the cluster as the total match value. As an example, if a use case defines a `ChargingStation` and a `PlugInElectricVehiclesPEV`, the cluster from Figure 4.4 will be recommended. In addition, with the simple search algorithm, it is realizable as well to recommend more than one cluster.

Prototypical coupling to the Power System Automation Language

To be able to validate the enhanced smart grid engineering based on machine learning approach by an example, a prototype will be embedded into PSAL. Hereby, the implementation is based on the programming language JAVA in an Eclipse based environment and its open source framework Xtext. Thus, the prototype can be encapsulated as a plug-in without changing source code of other integrated framework features. In regard to the outlined clustermodel and the search algorithm the architecture of this plug-in is illustrated in the class diagram in Figure 4.5.

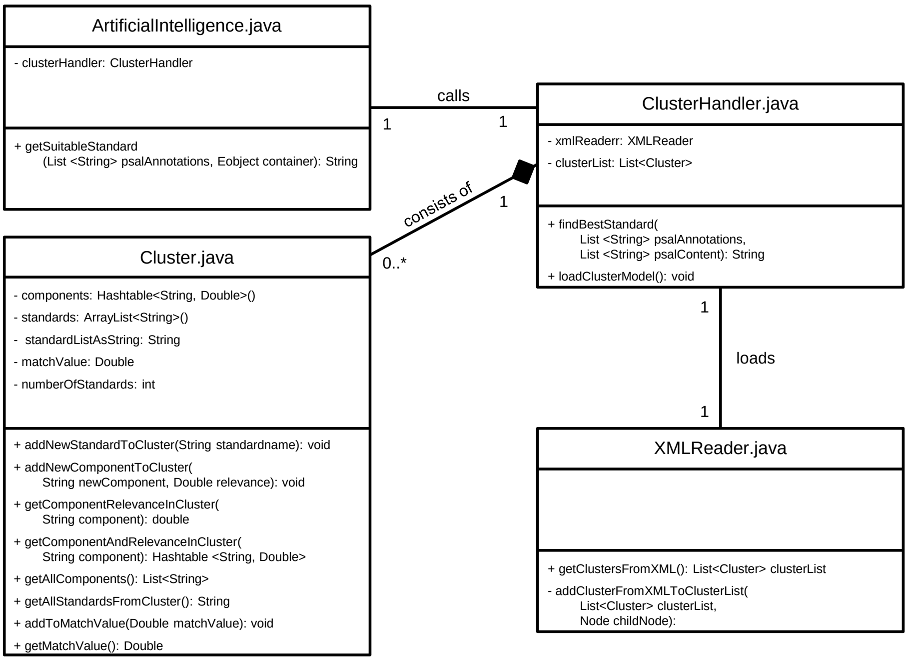


Figure 4.5.: Class diagram representing the architecture of the tool prototype

Describing the architecture on a manner, that is highly related to the sequential invoking process, while PSAL is started, the initialization of this plug-in is triggered, whereby with the instantiation of the object from the class `ArtificialIntelligence.java`, within its constructor the object of the `ClusterHandler.java` is instantiated as well and the method `loadClusterModel()` calls the `XMLReader.java`, whereby the clustermodel will be transferred to an instance of List<Cluster>. Since the initialization process is finalized, each time, the user modified his work within PSAL, the method `getSuitableStandard(...)` is called with the parameter of the updated use case (`psalAnnotations` represent the domain and zone areas, wherby with the `container` the defined components are extractable). In regard to this method, the introduced search algorithm is implemented in the `ClusterHandler.java` and returns all standard names as a string, which can be viewed in the user interface, that is provided by the Xtext framework. The used algorithm, identifies the match values by the attribues of each `Cluster.java` instance within the `clusterList`. After that final step, the references to all objects and espescially the list of clusters stay in PSAL, whereby on the next search request the resources are not loaded a second time and only the search algorithm influences the software speed.

The overall outcome is captured in Figure 4.6, the user interface of PSAL consists of several views, whereby the core element is the editor, fulfilling the major area of the interface. The yellow colored pop-up outlines the current related cluster of this use case. This visualization only appears by moving the cursor on one of the varibale names. Needless to say the visualization can be enhanced by the description or other graphical approaches.

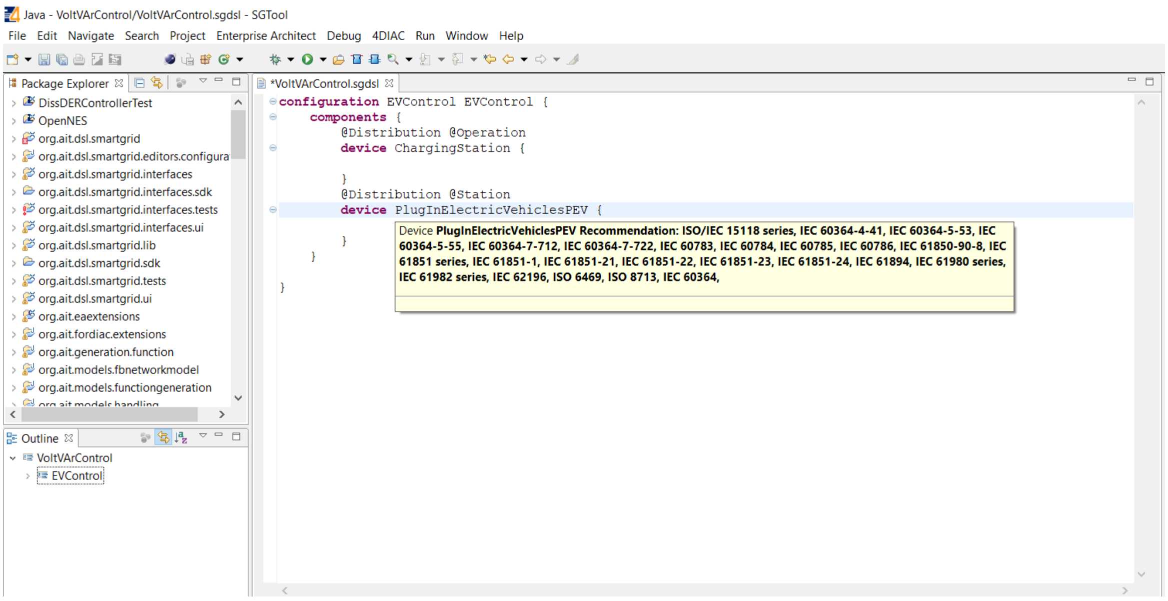


Figure 4.6.: Screenshot of the User Interface from PSAL with the enhancement of the tool prototype based on an unsupervised machine learning clustering approach

4.3. Results and Discussion

In this work, a domain specific supporting tool prototype based on unsupervised machine learning for identifying suitable standards, which are relevant to a specific cyber-physical-energy-systems implementation, is introduced. Within this section, the prototype will be evaluated in regard to the requirements from Section 1.2 and afterwards discussed in an critical context.

4.3.1. Evaluating the Introduced Concept through the Requirements

Evaluating the introduced tool prototype for a domain driven expert system, this approach can be evaluated by the requirements Table 1.1 from Section 1.2.

C1: On the specific implementation adapting domain information

Through the PSAL syntax, domain specific variable names and annotations are automatically extractable for elaborate a data set of the current design process through this tool prototype. With the environment of PSAL the user automatically requests the search algorithm of the enhanced smart grid engineering plug-in, while the user changes the source code or directly accesses the variable names.

C2: Recommendations based on domain specific information

Based on the requirement C1, the extracted data set and their information are directly accessable by the search algorithm, where the domain specific content will be used to identify the best suitable standard. Referring to Figure 4.5, the class diagram, in which the architecture for the recommendations based is illustrated, underlines the consideration of the dataset, thus the the use case representing data set will be compared to the cluster within the clustermodel.

C3: Human Machine Interface for recommendations

As illustrated in Figure 4.6, with the Xtext framework and the PSAL syntax, the recommendations are handed over on demand. Thereby the user comfort will not be influenced. As already mentioned there are different possibilities for enhancing the visualization of the recommendation window.

C4: Facilitated engineering for user

Due to the fact that this requirement is a not objective quantifiable requirement, which lies down that a recommendation at itself is not objective evaluable, within this work, the assertion that with this tool prototype suitable standards are easier to find for the use case can be made. Thereby the work effort of the engineer is reducible.

C5: No influence on the user-friendliness (measured on software speed)

Evaluating the user-friendliness, with the reference to Nah (2004) , who points out that "*0.1 second is about the limit for having the user feel that the system is reacting instantaneously*" the software speed, is measured over 200 times on a standard computer. For a from Xtext and PSAL nearly independent measurement, the time is measured between the request of the search function and the returned cluster. The result is plotted in Figure 4.7.

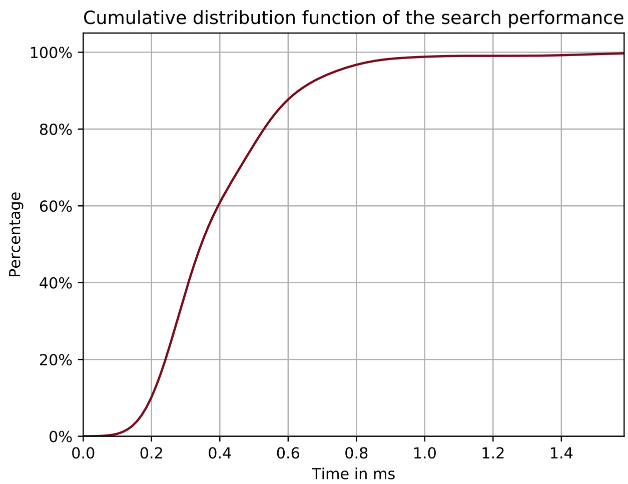


Figure 4.7.: Cumulative distribution function of the search performance measurements with the gaussian kernel density estimation

The overall resulting measurements from the cumulative distribution function shows that over 95 % of all searching requests took less than 0.8 ms. Further investigations shows, that the median $\widetilde{x}$ (at 50 %) of the more than 200 search-request is 0.321 ms, whereby the search algorithm took around 0.3 % of the maximum time of interaction. Furthermore with the standard derivation of $\sigma = 0.191\ ms$ the performance time is in relation to the median not greatly constant, but compared to the maximum time of interaction irrelevantly, as well as the maximum time of 1.582 ms.

4.3.2. Discussion Targeting on the Tool Prototype

With this tool prototype, an enhanced smart grid engineering system is realized and assists the engineer during the specification and engineering process. By means of such an machine learning approach, the working effort can be reduced, while at the same time, this domain driven supporting system provides a cluster of standards, which directly addresses the current use case, and, additionally, recommends standards which are useful in a wider sense. Referring to an overall supporting system, the implementation of all three concepts are mergeable to one. Indeed string metrics such as Jaro Winkler and others, compared in Cohen et al. (2003), will improve this supporting system, whereby the variable names are not limited to their name (i.e. "ChargingStation" and "ChrgngStation" has to be identified as the same). Although in this application the recommendations are helpful, further enhancements could consist of more information about each standard to provide deeper recommendations, but this is combined to the purchase of each standard. Concerning these contents, it is possible to delete or add new standards due to the human readable XML file. Even if some improvements could be done to fulfill a comprehensive tool, this tool prototype demonstrates how the engineering process can be enhanced.

5. Conclusion

Transferring the evaluated results and discussion into the overall context of this work, by scrutinizing the introduced answer to the research question "How can the engineering process be enhanced using machine learning", this chapter purposes the objective to summarize the achievements on a critical discussion approach. As the last point of this thesis, with the finalizing section, under the topic "outlook and future work", an view on further following research questions and related projects is represented.

5.1. Achievements and Overall Discussion

To conclude with this work, machine learning as a suitable technique for enhancing the smart grid engineering process is represented, especially between the specification and engineering phase. This assertion is underpinned with a literary research survey in the form of the state of the art in chapter 2 to be able to discuss and introduce concepts which lay down an machine learning approach or bases on an expert system. Within this discussion, relevant domains and research fields are regarded to point out the feasibility of each concept concerning the power system engineering process. As the conclusion, the two approaches "User driven support system based on neural networks" and "Error avoidance System based on Expert Systems" are evaluated as feasible from the technical point of view. However, a domain driven supporting system, purposing the recommendation of standards, that are relevant to the defined use case, is not evaluable from the technical point of view or adaptable in regard to applications from the literature. Thereby, as a further sub-target, in this work, algorithms are represented to identify structures in the large field of standards related to the smart grid domain. Using hierarchical clustering, an unsupervised machine learning approach, it is required to calculate the distance between two standards. For this issue, three equations are introduced as well in this work to be able to obtain a mathematical value ("distance") between these. These results are merged into the possible tool prototype, outlined in chapter 3, to face an evaluation for the "domain driven support system" as well. The outcome has its current version in form of an tool prototype, where the required enhancements are listed in Section 4.3.2 to be able to elaborate a holistic supporting software.

Although machine learning is presented as a suitable technique for enhancing the smart grid engineering process, a further outcome is that the usage of machine learning itself in combination with domain specific data sets has to be evaluated critical and comprehensive. Even if a structure is found, it has to be scrutinized if this outcome is reasonable. Precisely because it has to be avoided that in possible approaches the correlation in a data set are misinterpreted to a causality.

5.2. Outlook and Future Work

With regard to machine learning and in general artificial intelligence future applications in the power system domain will be rolled out. Under the topic "Future Trends for Big Data Application in Power Systems", Bessa (2018) concludes "*The Internet of Things and smart grids concepts can be realized from the technological point of view and the future challenges consist of data intelligent functions and new business models on top of the component, information and communication layers*". Thereof, it is underlined that with the emerging on new solutions based on machine learning and other artificial intelligence approaches further applications consists of similar research.

Pointing out the enhancement of the smart grid engineering support, new methods and application will emerge as well. As referred to in Section 2.1.4 and Chapter 3, this work is part of the Austrian project MESSE, in which the development of a concept for a model-based engineering and validation support system, covering the overall engineering process for smart grid applications - from use case design to validation and deployment is pursued (MESSE).

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A. Electronic Appendix

As a part of this thesis, an electronic appendix is available on the Compact Disc, which includes the source code of the introduced prototype, the list of standards and the thesis itself as a Portable Document Format file.

B. Considered Standards

Table B.1.: Considered standards with the corresponding descriptions

Standard	Description
IEC 60870-5-102	Telecontrol equipment and systems - Part 5: Transmission protocols - Section 102: Companion standard for the transmission of integrated totals in electric power systems
IEC 60870-5-103	Telecontrol equipment and systems - Part 5-103: Transmission protocols - Companion standard for the informative interface of protection equipment
IEC 60870-5-104	Telecontrol equipment and systems - Part 5-104: Transmission protocols - Network access for IEC 60870-5-101 using standardtransport profiles
IEC 60904 series	Photovoltaic devices - ALL PARTS
IEC 61131	Programmable controllers - ALL PARTS
IEC 61158 series	Industrial communication networks - Fieldbus specifications - Part 1: Overview and guidance for the IEC 61158 and IEC 61784 series
IEC 61334-4-32	Distribution automation using distribution line carrier systems - Part 4: Data communication protocols - Section 32: Data link layer - Logical link control (LLC)
IEC 61334-4-41	Distribution automation using distribution line carrier systems - Part 4: Data communication protocols - Section 41: Application protocol - Distribution line message specification
IEC 61334-4-511	Distribution automation using distribution line carrier systems - Part 4-511: Data communication protocols - Systems management - CIASE protocol
IEC 61334-4-512	Distribution automation using distribution line carrier systems - Part 4-512: Data communication protocols - System management using profile 61334-5-1 - Management Information Base (MIB)
IEC 61334-5-1	Distribution automation using distribution line carrier systems - Part 5-1: Lower layer profiles - The spread frequency shift keying (S-FSK) profile
IEC 61334-61	Covers the services required by the data communication protocol (DCP) network layer (N) sublayer entity at the logical interfaces with the N user layer and the LLC sublayer, using the connectionless N procedures.
IEC 61400-1	Wind turbines - Part 1: Design requirements
IEC 61400-2	Wind turbines - Part 2: Small wind turbines
IEC 61400-25-2	Wind turbines - Part 25-2: Communications for monitoring and control of wind power plants - Information models
IEC 61400-25-3	Wind turbines - Part 25-3: Communications for monitoring and control of wind power plants - Information exchange models
IEC 61400-25-4	Wind energy generation systems - Part 25-4: Communications for monitoring and control of wind power plants - Mapping to communication profile
IEC 61400-3	Wind turbines - Part 3: Design requirements for offshore wind turbines
IEC 61499	Function blocks
IEC 61724	Photovoltaic system performance - Part 1: Monitoring
IEC 61730	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction
IEC 61784	Industrial communication networks - Profiles
IEC 61784-1	Industrial communication networks - Profiles - Part 1: Fieldbus profiles
IEC 61836	Solar photovoltaic energy systems - Terms, definitions and symbols
IEC 61850-6	Communication networks and systems for power utility automation - Part 6: Configuration description language for communication in power utility automation systems related to IEDs
IEC 61850-7-1	Communication networks and systems for power utility automation - Part 7-1: Basic communication structure - Principles and models
IEC 61850-7-2	Communication networks and systems for power utility automation - Part 7-2: Basic information and communication structure - Abstract communication service interface (ACSI)
IEC 61850-7-3	Communication networks and systems for power utility automation - Part 7-3: Basic communication structure - Common data classes
IEC 61850-7-4	Communication networks and systems for power utility automation - Part 7-4: Basic communication structure - Compatible logical node classes and data object classes

IEC 61850-7-410	Communication networks and systems for power utility automation - Part 7-410: Basic communication structure - Hydroelectric power plants - Communication for monitoring and control
IEC 61850-7-420	Communication networks and systems for power utility automation - Part 7-420: Basic communication structure - Distributed energy resources logical nodes
IEC 61850-8-1	Communication networks and systems for power utility automation - Part 8-1: Specific communication service mapping (SCSM) - Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IECÂ 8802-3
IEC 61850-8-2	Communication networks and systems for power utility automation - Part 8-2: Specific communication service mapping (SCSM) - Mapping to Extensible Messaging Presence Protocol (XMPP)
IEC 61850-80-4	Communication networks and systems for power utility automation - Part 80-4: Translation from the COSEM object model (IEC 62056) to the IEC 61850 data model
IEC 61850-9-2	Communication networks and systems for power utility automation - Part 9-2: Specific communication service mapping (SCSM) - Sampled values over ISO/IEC 8802-3
IEC 61850-90-1	Communication networks and systems for power utility automation - Part 90-1: Use of IEC 61850 for the communication between substations
IEC 61850-90-10	Communication networks and systems for power utility automation - Part 90-10: Models for scheduling
IEC 61850-90-11	Communication networks and systems for power utility automation - Part 90-11: Methodologies for modelling of logics for IEC 61850 based applications.
IEC 61850-90-12	Communication networks and systems for power utility automation - Part 90-12: Wide area network engineering guidelines
IEC 61850-90-15	Communication networks and systems for power utility automation - Part 90-15: Hierarchical architecture of a DER system
IEC 61850-90-2	Communication networks and systems for power utility automation - Part 90-2: Using IEC 61850 for communication between substations and control centres
IEC 61850-90-4	Communication networks and systems for power utility automation - Part 90-4: Network engineering guidelines
IEC 61850-90-5	Communication networks and systems for power utility automation - Part 90-5: Use of IEC 61850 to transmit synchrophasor information according to IEEE C37.118
IEC 61850-90-7	Communication networks and systems for power utility automation - Part 90-7: Object models for power converters in distributed energy resources (DER) systems
IEC 61850-90-9	Communication networks and systems for power utility automation - Part 90-9: Object Models for Batteries
IEC 61968 series	Application integration at electric utilities - System interfaces for distribution management - Part 1: Interface architecture and general recommendations
IEC 61968-100	Application integration at electric utilities - System interfaces for distribution management - Part 100: Implementation profiles
IEC 61970 series	Energy management system application program interface (EMS-API) - ALL PARTS
IEC 62056-1-0	Electricity metering data exchange - The DLMS/COSEM suite - Part 1-0: Smart metering standardisation framework
IEC 62056-3-1	Electricity metering data exchange - The DLMS/COSEM suite - Part 3-1: Use of local area networks on twisted pair with carrier signalling
IEC 62056-3-2	Electricity metering data exchange - The DLMS/COSEM suite - Part 3-2: Local interface using twisted pair with carrier signaling
IEC 62056-31	Electricity metering - Data exchange for meter reading, tariff and load control - Part 31: Use of local area networks on twisted pair with carrier signalling
IEC 62056-4-7	Electricity metering data exchange - The DLMS/COSEM suite - Part 4-7: DLMS/COSEM transport layer for IP networks
IEC 62056-42	Electricity metering - Data exchange for meter reading, tariff and load control - Part 42: Physical layer services and procedures for connection-oriented asynchronous data exchange
IEC 62056-46	Electricity metering - Data exchange for meter reading, tariff and load control - Part 46: Data link layer using HDLC protocol
IEC 62056-47	Electricity metering - Data exchange for meter reading, tariff and load control - Part 47: COSEM transport layers for IPv4 network
IEC 62056-5-3	Electrcity metering data exchange - The DLMS/COSEM suite - Part 5-3: DLMS/COSEM application layer
IEC 62056-5-8	Description Not available at present
IEC 62056-53	Electricity metering - Data exchange for meter reading, tariff and load control - Part 53: COSEM application layer
IEC 62056-6-1	Electricity metering data exchange - The DLMS/COSEM suite - Part 6-1: Object Identification System (OBIS)
IEC 62056-6-2	Electricity metering data exchange - The DLMS/COSEM suite - Part 6-2: COSEM interface classes
IEC 62056-6-9	Electricity metering data exchange - The DLMS/COSEM suite - Part 6-9: Mapping between the Common Information Model message profiles (IEC 61968-9) and DLMS/COSEM (IEC 62056) data models and protocols
IEC 62056-7-6	Electricity metering data exchange - The DLMS/COSEM suite - Part 7-6: The 3-layer, connection-oriented HDLC based communication profile
IEC 62056-8-3	Electricity metering data exchange - The DLMS/COSEM suite - Part 8-3: Communication profile for PLC S-FSK neighbourhood networks

IEC 62056-9-7	Electricity metering data exchange - The DLMS/COSEM suite - Part 9-7: Communication profile for TCP-UDP/IP networks
IEC 62282	Fuel cell technologies - Part 2: Fuel cell modules
IEC 62325 series	Framework for energy market communications - Part 301: Common information model (CIM) extensions for markets
IEC 62351 series	Power systems management and associated information exchange - Data and communications security - ALL PARTS
IEC 62439	Industrial communication networks - High availability automationnetworks - Part 1: General concepts and calculation methods
IEC 62488-1 (Formerly EN60663) - Part 1	Power line communication systems for power utility applications - Part 1: Planning of analogue and digital power line carrier systems operating over EHV/HV/MV electricity grids
IEC 62541 series	OPC unified architecture - Part 3: Address Space Model
ISO 16484 series	Building automation and control systems (BACS)
ISO/IEC 12139-1	Information technology – Telecommunications and information exchange between systems – Powerline communication (PLC) – High speed PLC medium access control (MAC) and physical layer (PHY) – Part 1: General requirements
ISO/IEC 14543-3	Information technology - Home electronic system (HES) architecture - Part 3-1: Communication layers - Application layer for network based control of HES Class 1
ISO/IEC 14543-3 series	Information technology - Home electronic system (HES) architecture - Part 3-1: Communication layers - Application layer for network based control of HES Class 1
ISO/IEC 14908 series	Information technology – Control network protocol – Part 1: Protocol stack
ISO/IEC 14908-1	Information technology – Control network protocol – Part 1: Protocol stack
ISO/IEC 14908-2	Information technology – Control network protocol – Part 2: Twisted pair communication
ISO/IEC 14908-3	Information technology – Control network protocol – Part 3: Power line channel specification
ISO/IEC 14908-4	Information technology – Control network protocol – Part 4: IP communication
ISO/IEC 15802 IEEE 802.1	Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Common specifications
ISO/IEC 7498-1	Information technology – Open Systems Interconnection – Basic Reference Model: The Basic Model
ISO/IEC 8802-3	Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Standard for Ethernet
ITU-T G.7041	Generic Framing Procedure (GFP)
ITU-T G.7042	Link capacity adjustment scheme (LCAS) for virtual concatenated signals
ITU-T G.707	Network node interface for the synchronous digital hierarchy (SDH)
ITU-T G.709	Interfaces for the optical transport network
ITU-T G.781	Synchronization layer functions
ITU-T G.783	Characteristics of synchronous digital hierarchy (SDH) equipment functional blocks
ITU-T G.798	Characteristics of optical transport network hierarchy equipment functional blocks
ITU-T G.803	Architecture of transport networks based on the synchronous digital hierarchy (SDH)
ITU-T G.872	Architecture of optical transport networks
ITU-T G.983.1	Broadband optical access systems based on Passive Optical Networks (PON)
ITU-T G.983.2	ONT management and control interface specification for B-PON
ITU-T G.983.3	A broadband optical access system with increased service capability by wavelength allocation
ITU-T G.983.4	A broadband optical access system with increased service capability using dynamic bandwidth assignment
ITU-T G.983.5	A broadband optical access system with enhanced survivability
ITU-T G.984.1	Gigabit-capable passive optical networks (GPON): General characteristics
ITU-T G.984.2	Gigabit-capable Passive Optical Networks (G-PON): Physical Media Dependent (PMD) layer specification
ITU-T G.984.3	Gigabit-capable passive optical networks (G-PON): Transmission convergence layer specification
ITU-T G.984.4	Gigabit-capable passive optical networks (G-PON): ONT management and control interface specification
ITU-T G.984.5	Gigabit-capable passive optical networks (G-PON): Enhancement band
ITU-T G.984.6	Gigabit-capable passive optical networks (GPON): Reach extension
ITU-T G.984.7	Gigabit-capable passive optical networks (GPON): Long reach
ITU-T G.987.1	10-Gigabit-capable passive optical networks (XG-PON): General requirements
ITU-T G.987.2	10-Gigabit-capable passive optical networks (XG-PON): Physical media dependent (PMD) layer specification
ITU-T G.987.3	10-Gigabit-capable passive optical networks (XG-PON): Transmission convergence (TC) layer specification
ITU-T G.9901	Narrowband orthogonal frequency division multiplexing power line communication transceivers - Power spectral density specification
ITU-T G.9902	Narrowband orthogonal frequency division multiplexing power line communication transceivers for ITU-T G.hnem networks

ITU-T G.9903	Narrowband orthogonal frequency division multiplexing power line communication transceivers for G3-PLC networks
ITU-T G.9904	Narrowband orthogonal frequency division multiplexing power line communication transceivers for PRIME networks
ITU-T G.991.1	High bit rate digital subscriber line (HDSL) transceivers
ITU-T G.991.2	Single-pair high-speed digital subscriber line (SHDSL) transceivers
ITU-T G.992.1	Asymmetric digital subscriber line (ADSL) transceivers
ITU-T G.992.2	Splitterless asymmetric digital subscriber line (ADSL) transceivers
ITU-T G.992.3	Asymmetric digital subscriber line transceivers 2 (ADSL2)
ITU-T G.992.4	Splitterless asymmetric digital subscriber line transceivers 2 (splitterless ADSL2)
ITU-T G.993.1	Very high speed digital subscriber line transceivers (VDSL)
ITU-T G.993.2	Very high speed digital subscriber line transceivers 2 (VDSL2)
ITU-T G.993.5	Self-FEXT cancellation (vectoring) for use with VDSL2 transceivers
ITU-T G.994.1	Handshake procedures for digital subscriber line transceivers
ITU-T G.995.1	Overview of digital subscriber line (DSL) Recommendations
ITU-T G.996.1	Test procedures for digital subscriber line (DSL) transceivers
ITU-T G.996.2	Single-ended line testing for digital subscriber lines (DSL)
ITU-T G.9960 (PHY)	Unified high-speed wireline-based home networking transceivers - System architecture and physical layer specification
ITU-T G.9961 (DLL)	Unified high-speed wireline-based home networking transceivers - Data link layer specification
ITU-T G.9962 (MIMO)	Description Not available at present
ITU-T G.9964 (PSD)	Unified high-speed wireline-based home networking transceivers - Power spectral density specification
ITU-T G.997.1	Physical layer management for digital subscriber line transceivers
ITU-T G.998.1	ATM-based multi-pair bonding
ITU-T G.998.2	Ethernet-based multi-pair bonding
ITU-T G.998.3	Multi-pair bonding using time-division inverse multiplexing
ITU-T G.998.4	Improved impulse noise protection for digital subscriber line (DSL) transceivers
ITU-T G.999.1	Interface between the link layer and the physical layer for digital subscriber line (DSL) transceivers
IEC 60870-5-101	Telecontrol equipment and systems - Part 5-101: Transmissionprotocols - Companion standard for basic telecontrol tasks
IEC 60870-5-5	Telecontrol equipment and systems - Part 5: Transmission protocols - Section 5: Basic application functions
IEC 61400-25	Wind energy generation systems
IEC 61588 (IEEE 1588)	Precision Clock Synchronization Protocol for Networked Measurement and Control Systems
IEC 61850 series	Communication networks and systems for power utility automation - ALL PARTS
IEC 62056 series	Electricity metering data exchange - The DLMS/COSEM suite - Part 1-0: Smart metering standardisation framework
IEC 62351-1	Power systems management and associated information exchange - Data and communications security - Part 1: Communication network and system security - Introduction to security issues
IEC 62351-10	Power systems management and associated information exchange - Data and communications security - Part 10: Security architecture guidelines
IEC 62351-11	Power systems management and associated information exchange - Data and communications security - Part 11: Security for XML documents
IEC 62351-2	Power systems management and associated information exchange - Data and communications security - Part 2: Glossary of terms
IEC 62351-3	Power systems management and associated information exchange - Data and communications security - Part 3: Communication network and system security - Profiles including TCP/IP
IEC 62351-4	Power systems management and associated information exchange - Data and communications security - Part 4: Profiles including MMS and derivatives
IEC 62351-5	Power systems management and associated information exchange - Data and communications security - Part 5: Security for IEC 60870-5 and derivatives
IEC 62351-6	Power systems management and associated information exchange - Data and communications security - Part 6: Security for IEC 61850
IEC 62351-7	Power systems management and associated information exchange - Data and communications security - Part 7: Network and System Management (NSM) data object models
IEC 62351-8	Power systems management and associated information exchange - Data and communications security - Part 8: Role-based access control

IEC 62351-9	Power systems management and associated information exchange - Data and communications security - Part 9: Cyber security key management for power system equipment
IEC 62361 series	Power systems management and associated information exchange - Interoperability in the long term - Part 2: End to end quality codes for supervisory control and data acquisition (SCADA)
IEC 62361-102	Power systems management and associated information exchange - Interoperability in the long term - Part 102: CIM - IEC 61850 harmonization
IEC 62443 series	Industrial communication networks - Network and system security - Part 2-1: Establishing an industrial automation and control system security program
ISO 8601	Description to represent dates and times
ISO/IEC 15118	Road Vehicles - Vehicle-to-Grid Communication Interface
ISO/IEC 27001	Information technology – Security techniques – Information security management systems – Requirements
ISO/IEC 27002	Information technology – Security techniques – Code of practice for information security controls
IEC 60364	Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions
IEC 60870 series	Telecontrol equipment and systems - Part 5: Transmission protocols - ALL PARTS
IEC 62394	Service diagnostic interface for consumer electronics products and networks - Implementation for ECHONET
IEC 62457	Multimedia home networks - Home network communication protocol over IP for multimedia household appliances
IEC 62480	Multimedia home network - Network interfaces for network adapter
ISO 17800	Facility smart grid information model
ISO/IEC 14543	Information technology - Home electronic system (HES) architecture - Part 2-1: Introduction and device modularity
ISO/IEC 14543-4	Information technology - Home electronic system (HES) architecture - Part 4: Home and building automation in a mixed-use building
ISO/IEC 15045	Information technology - Home electronic system (HES) gateway - Part 1: A residential gateway model for HES
ISO/IEC 15067-3	Information technology - Home electronic system (HES) application model - Part 3: Model of a demand-response energy management system for HES
ISO/IEC 18012	Information technology - Home electronic system - Guidelines for product interoperability - Part 1: Introduction
ISO/IEC 24767	Information technology - Home network security - Part 1: Security requirements
IEC 60076	Power transformers
IEC 60193	Hydraulic turbines, storage pumps and pump-turbines - Model acceptance tests
IEC 60255	Measuring relays and protection equipment - Part 1: Common requirements
IEC 60870-6	Telecontrol equipment and systems - Part 6: Telecontrol protocols compatible with ISO standards and ITU-T recommendations
IEC 61000 Series	Electromagnetic compatibility (EMC) - Part 3: Limit - ALL PARTS
IEC 61000-2-12	Telecontrol equipment and systems - Part 6: Telecontrol protocols compatible with ISO standards and ITU-T recommendations
IEC 61000-2-2	Electromagnetic compatibility (EMC) - Part 2-12: Environment - Compatibility levels for low-frequency conducted disturbances and signalling in public medium-voltage power supply systems
IEC 61000-3-13	Electromagnetic compatibility (EMC) - Part 3-13: Limits - Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems
IEC 61000-3-14	Electromagnetic compatibility (EMC) - Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems
IEC 61000-3-15	Electromagnetic compatibility (EMC) - Part 3-15: Limits - Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network
IEC 61000-3-6	Electromagnetic compatibility (EMC) - Part 3-6: Limits - Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems
IEC 61000-3-7	Electromagnetic compatibility (EMC) - Part 3-7: Limits - Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power system
IEC 61000-4-19	Electromagnetic compatibility (EMC) - Part 4-19: Testing and measurement techniques - Test for immunity to conducted, differential mode disturbances and signalling in the frequency range 2 kHz to 150 kHz at a.c. power ports
IEC 61000-4-30	Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods
IEC 61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments
IEC 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments
IEC 61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
IEC 61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments

IEC 61000-6-5	Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for equipment used in power station and substation environment
IEC 61326	Electrical equipment for measurement, control and laboratory use
IEC 61360	Standard data element types with associated classification scheme - Part 1: Definitions - Principles and methods
IEC 61400 series	Wind turbines
IEC 61512	Batch control - Part 1: Models and terminology
IEC 61727	Photovoltaic (PV) systems - Characteristics of the utility interface
IEC 61804	Function blocks (FB) for process control and electronic device description language (EDDL) - Part 2: Specification of FB concept
IEC 61850-80-1	Communication networks and systems for power utility automation - Part 80-1: Guideline to exchanging information from a CDC-based data model using IEC 60870-5-101 or IEC 60870-5-104
IEC 61850-90-13	Communication networks and systems for power utility automation - Part 90-13: Deterministic networking technologies
IEC 61850-90-3	Communication networks and systems for power utility automation - Part 90-3: Using IEC 61850 for condition monitoring diagnosis and analysis
IEC 61869	Instrument transformers - Part 1: General requirements
IEC 61897	Overhead lines - Requirements and tests for Stockbridge type aeolian vibration dampers
IEC 61968-1	Application integration at electric utilities - System interfaces for distribution management - Part 1: Interface architecture and general recommendations
IEC 61968-11	Application integration at electric utilities - System interfaces for distribution management - Part 11: Common information model (CIM) extensions for distribution
IEC 61968-13	Application integration at electric utilities - System interfaces for distribution management - Part 13: CIM RDF Model exchange format for distribution
IEC 61968-2	Application integration at electric utilities - System interfaces for distribution management - Part 2: Glossary
IEC 61968-3	Application integration at electric utilities - System interfaces for distribution management - Part 3: Interface for network operations
IEC 61968-4	Application integration at electric utilities - System interfaces for distribution management - Part 4: Interfaces for records and asset management
IEC 61968-6	Application integration at electric utilities - System interfaces for distribution management - Part 6: Interfaces for maintenance and construction
IEC 61968-8	Application integration at electric utilities - System interfaces for distribution management - Part 8: Interfaces for customer operations
IEC 61968-9	Application integration at electric utilities - System interfaces for distribution management - Part 9: Interfaces for meter reading and control
IEC 61970-1	Energy management system application program interface (EMS-API) - Part 1: Guidelines and general requirements
IEC 61970-2	Energy management system application program interface (EMS-API) - Part 2: Glossary
IEC 61970-301	Energy management system application program interface (EMS-API) - Part 301: Common information model (CIM) base
IEC 61970-401	Energy management system application program interface (EMS-API) - Part 401: Component interface specification (CIS) framework
IEC 61970-452	Energy management system application program interface (EMS-API) - Part 452: CIM static transmission network model profiles
IEC 61970-453	Energy management system application program interface (EMS-API) - Part 453: Diagram layout profile
IEC 61970-456	Energy management system application program interface (EMS-API) - Part 456: Solved power system state profiles
IEC 61970-458	Energy management system application program interface (EMS-API) - Part 458: Common information model (CIM) extension to generation
IEC 61970-501	Energy management system application program interface (EMS-API) - Part 501: Common Information Model Resource Description Framework (CIM RDF) schema
IEC 61970-502-8	Energy Management System Application Program Interface (EMS-API) - Part 502-8: Web Services Profile for 61970-4 Abstract Services
IEC 61970-552	Energy management system application program interface (EMS-API) - Part 552: CIMXML Model exchange format
IEC 61987	Industrial-process measurement and control - Data structures and elements in process equipment catalogues - Part 1: Measuring equipment with analogue and digital output
IEC 62264	Enterprise-control system integration - Part 1: Models and terminology
IEC 62271-1x series	High-voltage switchgear and controlgear - Part 1: Common specifications for alternating current switchgear and controlgear
IEC 62271-2x series	High-voltage switchgear and controlgear - Part 2: Seismic qualification for rated voltages of 72,5 kV and above
IEC 62282 series	Fuel cell technologies - Part 2: Fuel cell modules

IEC 62325	Framework for energy market communications - Part 301: Common information model (CIM) extensions for markets
IEC 62325-301	Framework for energy market communications - Part 301: Common information model (CIM) extensions for markets
IEC 62325-351	Framework for energy market communications - Part 351: CIM European market model exchange profile
IEC 62325-450	Framework for energy market communications - Part 450: Profile and context modelling rules
IEC 62325-451-1	Framework for energy market communications - Part 451-1: Acknowledgement business process and contextual model for CIM European market
IEC 62325-451-2	Framework for energy market communications - Part 451-2: Scheduling business process and contextual model for CIM European market
IEC 62325-451-3	Framework for energy market communications - Part 451-3: Transmission capacity allocation business process (explicit or implicit auction) and contextual models for European market
IEC 62357	Power systems management and associated information exchange
IEC 62361-100	Power systems management and associated information exchange - Interoperability in the long term - Part 100: CIM profiles to XML schema mapping
IEC 62361-101	Power systems management and associated information exchange - Interoperability in the long term - Part 101: Common Information Model Profiles (IEC 57/1343/CD:2013)
IEC 62446	Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection
IEC 62541-1	OPC Unified Architecture - Part 10: Programs
IEC 62541-10	OPC Unified Architecture - Part 10: Programs
IEC 62541-2	OPC Unified architecture - Part 2: Security Model
IEC 62541-3	OPC Unified architecture - Part 3: Address Space Model
IEC 62541-4	OPC Unified Architecture - Part 4: Services
IEC 62541-5	OPC Unified Architecture - Part 5: Information Model
IEC 62541-6	OPC Unified architecture - Part 6: Mappings
IEC 62541-7	OPC Unified architecture - Part 7: Profiles
IEC 62541-8	OPC Unified Architecture - Part 8: Data Access
IEC 62541-9	OPC Unified Architecture - Part 9: Alarms and conditions
ISO 19142	Geographic information – Web Feature Service
ISO 81400	Wind turbines
ISO 8601 (IEC 28601)	Date and time format
IEC 62872 Ed. 1.0	Industrial-process measurement, control and automation system interface between industrial facilities and the smart grid
IEC 62325-503	Framework for energy market communications - Part 503: Market data exchanges guidelines for the IEC 62325-351 profile
IEC 60255-24	Measuring relays and protection equipment - Part 24: Common format for transient data exchange (COMTRADE) for power systems
IEC 61850-90-6	Communication networks and systems for power utility automation - Part 90-6: Use of IEC 61850 for Distribution Automation Systems
IEC 62271-3	High-voltage switchgear and controlgear - Part 3: Digital interfaces based on IEC 61850
IEC 60227	Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V - Part 1: General requirements
IEC 60502	Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um = 1,2 kV) up to 30 kV (Um = 36 kV) - Part 2: Cables for rated voltages from 6 kV (Um = 7,2 kV) up to 30 kV (Um= 36 kV)
IEC 60811	Electric and optical fibre cables - Test methods for non-metallic materials - Part 100: General
IEC 60840	Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um = 36 kV) up to 150 kV (Um = 170 kV) - Test methods and requirements
IEC 60364-4-41	Low voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock 60364-4-41:2005
IEC 60364-5-53	Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - Isolation, switching and control
IEC 60364-5-55	Electrical installations of buildings - Part 5-55: Selection and erection of electrical equipment - Other equipment
IEC 60364-7-712	Low voltage electrical installations - Part 7-712: Requirements for special installations or locations - Solar photo-voltaic (PV) power supply systems
IEC 60364-7-722	Low-voltage electrical installations - Part 7-722: Requirements for special installations or locations - Supplies for electric vehicles
IEC 60783	Wiring and connectors for electric road vehicles
IEC 60784	Instrumentation for electric road vehicles
IEC 60785	Rotating machines for electric road vehicles
IEC 60786	Controllers for electric road vehicles

IEC 61850-90-8	Communication networks and systems for power utility automation - Part 90-8: Object model for E-mobility
IEC 61851 series	Electric vehicle conductive charging system - Part 1: General requirements
IEC 61851-1	Electric vehicle conductive charging system - Part 1: General requirements
IEC 61851-21	Electric vehicle conductive charging system - Part 21-1 Electric vehicle on-board charger EMC requirements for conductive connection to AC/DC supply
IEC 61851-22	Electric vehicle conductive charging system - Part 22: AC electric vehicle charging station
IEC 61851-23	Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station
IEC 61851-24	Electric vehicle conductive charging system - Part 24: Digital communication between a d.c. EV charging station and an electric vehicle for control of d.c. charging
IEC 61894	Description Not available at present
IEC 61980 series	Electric vehicle wireless power transfer (WPT) systems - Part 1: General requirements
IEC 61982 series	Secondary batteries (except lithium) for the propulsion of electric road vehicles - Performance and endurance tests
IEC 62196	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements
ISO 6469	Electrically propelled road vehicles – Safety specifications
ISO 8713	Electrically propelled road vehicles
ISO/IEC 15118 series	Road Vehicles - Vehicle-to-Grid Communication Interface
IEC 60633	Terminology for high-voltage direct current (HVDC) transmission
IEC 60700-1	Thyristor valves for high voltage direct current (HVDC) power transmission - Part 1: Electrical testing
IEC 60919	Performance of high-voltage direct current (HVDC) systems with line-commutated converters
IEC 61803	Determination of power losses in high-voltage direct current (HVDC)converter stations with line-commutated converters
IEC 61850-90-14	Communication networks and systems for power utility automation - Part 90-14: Using IEC 61850 for FACTS (Flexible AC Transmission Systems) data modelling has been published as draft for comments of the industry
IEC 61954	Static var compensators (SVC) - Testing of thyristor valves
CISPR 11	Industrial, scientific and medical equipment - Radio-frequency disturbance characteristics - Limits and methods of measurement
CISPR 12	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers
CISPR 13	Sound and television broadcast receivers and associated equipment - Radio disturbance characteristics - Limits and methods of measurement
CISPR 14-1	Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 1: Emission
CISPR 15	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
CISPR 16 Series	Specification for radio disturbance and immunity measuring apparatus and methods
CISPR 22	Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement
CISPR 25	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers
CISPR 32	Electromagnetic compatibility of multimedia equipment - Emission requirements
IEC 60794-2	Optical fibre cables - Part 2: Indoor cables - Sectional specification
IEC 60794-4	Optical fibre cables - Part 4: Sectional specification - Aerial optical cables along electrical power lines

Glossar

AI	Artificial Intelligence
ANN	Artificial Neural Network
FAT	Factory Acceptance Test
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
MESSE	Model-based Engineering and Validation Support for Cyber-Physical Energy Systems
PSAL	Power System Automation Language
SAT	Site Acceptance Test
SGAM	Smart Grid Architecture Model
UML	Unified Modeling Language
XML	Extensible Markup Language

Declaration

I declare within the meaning of section 25(4) of the Examination and Study Regulations of the International Degree Course Information Engineering that: this Bachelor report has been completed by myself independently without outside help and only the defined sources and study aids were used. Sections that reflect the thoughts or works of others are made known through the definition of sources.

Hamburg, January 15, 2019

City, Date

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