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The new era of technology in energy sector

Ewa Mataczyńska , Cyprian Mataczyński***

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Abstract

Modern energy companies are overloaded with data, providing numerous insights into the systems. The data is collected not only from the devices which are the property of the enterprise, but mainly from the enterprises' environment. The need to collect this data and process it correctly comes from the transformation of the energy sector in which the new decentralized energy resources are more and more common, rise of the client requirements and the pressure on reducing the impact on the environment. Having such amount of data, without the aid of the new autonomous technologies, it seems impossible to effectively use it. The aid comes from the broad spectrum of artificial intelligence algorithms. Creation of learning models, set to solve specific problems might one day lead to single and unified platform, which autonomously (and on-line) will identify and solve appearing problems. This article's analysis aims to acquaint the reader with the aspects of the use of machine learning based methods used to aid a few chosen energy market processes. Shown solutions are mainly author's view on how the mentioned algorithms may be useful in sector's expectations of the future.

1. Introduction

Artificial Intelligence (AI) is one of the greatest technological trends of the present time, shaping future business models in all sectors of the economy around the world. Thanks to the great progress in the development of computer technology, artificial intelligence is reaching new levels of usability and applications, exceeding all initial expectations.

Using advanced machine learning (ML) and deep learning (DL) algorithms as well as artificial neural networks (ANN), AI can handle huge amounts not only structured data but also unstructured or partly structured, from various sources. It can identify patterns and relationships between the data, but also attempt to predict possible scenarios while creating recommendations

** dr Ewa Mataczyńska – Ignacy Łukasiewicz Energy Policy Institute expert*
*** Cyprian Mataczyński – Department of Control Systems and Mechatronics, Wroclaw University of science and technology*

for decision makers managing a given process. Intelligent applications can also effectively make decisions autonomously and automatically, without human intervention.

The problem of modern companies is that they operate in an environment saturated with data carrying huge amounts of various information. The data comes from both, devices owned by the companies themselves, but mostly from the environment in which they operate. It happens that potentially irrelevant (not related to the company's operations) information can significantly affect the implementation of individual business processes through various types of relationships (difficult to define by a human). This means that, despite being aware of this information, the company is unable to use it effectively and efficiently. In this situation, the issue of how to obtain and properly process information in an ever-changing environment is gaining value. With huge amounts of data, which seems impossible to be cataloged, the company will not function effectively without the support of new technologies. Artificial intelligence techniques and algorithms will certainly bring such support. They are increasingly used in the energy sector. Their applications are directed at the identification of advanced problems, for which a complex analysis of large amounts of data is necessary. In addition, methods aiming to solve this problem should be able to adapt to the time-varying environmental conditions understood as data variation (model generalization).

The following article aims to showcase the possible machine learning techniques to develop models supporting solutions to selected problems in the energy sector. It should be assumed that the starting point enabling the topic of possible application of the indicated solutions to be considered is the point at which the enterprise has:

- enough data necessary for the proper functioning of the model,
- adequate technological and technical facilities, enabling data collection, storing, and analyzing,
- the necessary human resources to effectively implement and manage new process' models that will shape after the implementation of individual solutions.

The article also does not deal with the financial issues of the possible launching and functioning of the analyzed solutions. Due to the lack of current infrastructure, data and conducted research, as well as the advancement of the presented problems, the material should be treated as support for the development of future projects or implementations of target solutions in the energy sector. The solutions presented in it are for the most part proprietary examples of how can you try to approach existing expectations in the sector.

2. The transformation of energy sector as the main factor for AI development.

For several years there have been intensive discussions on the use of artificial intelligence to support processes related to the functioning of the energy sector, in particular the electricity market. The transformation process has started on this market, the source of which is decentralization, decarbonization and digitization. These three elements closely related to each other determine the future directions for the sector. These elements cannot be treated separately because in order to achieve a certain level of decarbonization, decentralized resources should be involved, but in order to effectively use these resources, digitization mechanisms are necessary to manage these resources in a way, that achieves the highest level of energy efficiency on the one hand, and enable decentralized resources to operate in a manner that guarantees the maintenance of stable and secure operation of the power system, on the other. Of course, this is a simplified scheme, in the depths of which there are numerous specific tasks that will have to be carried out to achieve the intended goal. In addition, these are not only tasks, but also new business models for large energy companies, a new entities entering the market, a change in consumer behavior, which will also be important. Finally, it is a change in the needs of these customers, the needs of everyday life, which has evolved with the rise of new solutions for the home (smart home). Such a wide range of behaviors, changes and needs indicates the need to approach the issue of transformation in the energy sector in a comprehensive manner.

The development of learning models focused on solving specific issues and problems can finally be combined into one complete platform, that will automatically (also on-line) identify and solve emerging problems. Creating an architecture for such a platform that will cover both technical and economic perspectives for the energy sector development with AI support, seems to be the right direction for the future electricity market saturated with distributed sources (i.e. PVs, wind turbines, electric cars, energy storages, micro grids, heat pumps, consumers managing their energy consumption) with very different characteristics, affecting the stability of the entire power system. Without changing existing technologies, it will be difficult to manage large amounts of diverse data. For this reason, AI seemed to be great potential for designing the future shape of the energy market.

3. Selected areas of AI application in the energy sector

Typical areas of application for this type of technology are electricity trading, smart grid or sector coupling. The condition of using AI in the energy system is the digitization of the sector and a properly collected and stored large set of reliable data. For the majority of currently used solutions, data should be described by a human (labeled) in a way that allows to perform the task for which the given algorithm is to be used (whether for a regression, classification or other task). In this case, we are talking about supervised learning, consisting of giving examples of correct operation, which a properly configured model should be able to repeat, however mainaining the generalization when receiving data from outside the training dataset(e.g. taken from other devices). Therefore, in this case, the reliability of the data on the basis of which the model will be learned is important.

Proper analysis of the data coming from devices installed in power networks can help in predicting failures, forecasting electricity demand and responding in advance to emerging problems with system imbalance. Depending on the cause of the failure, specially developed platforms will be able to use the right models to analyze and trigger response mechanisms to eliminate the risk of failure. In this case, in addition to the typical classic optimization approach, in the future we can try to use reinforcement learning models for which data is not as crucial, as more precise simulations of systems and environments for these algorithms. The most common application of self-learning models is making forecasts, which can also be used by producers, especially those who manage the production of energy from renewable energy installations (sun, wind), as well as companies dealing with the sale of electricity. The latter often use specialized models not only to forecast energy demand, but also to predict price volatility on the energy market.

The automotive industry has particular expectations in the use of AI solutions. The increase in the number of electric cars is on the one hand an opportunity (especially many perceived as support for climate solutions) on the other a challenge. Charging electric cars (especially when using high power) must be coordinated at the level of the electricity grid in a way that ensures first of all the efficient use of the charger by the car owner, and latter -

guarantees the stability of the power network, especially in the local context. An electric car is often defined as a future source of flexibility for the power system due to the technical possibilities of using it as an energy storage. The possibility of using this type of behavior on a large scale will require advanced models to manage the stability of the power grid.

Another application of AI solutions is anomaly detection in energy consumption, i.e. detection of illegal energy consumption. Some of these solutions work on the basis of unsupervised learning (neural network self-learning), i.e. based only on sample input data without labels entered by the teacher. A properly designed neural network can adjust the weights of its algorithm to automatically detect signals different from those that characterize a standard consumer. In other words, to identify potential signal lots that are characteristic of illegal energy consumption.

In addition, coordinating maintenance and determining optimal network maintenance times using AI helps minimize costs and loss of profits, and also eliminates unnecessary disruption to network operations.

4. Possibilities of implementing AI in the energy sector - selected issues

4.1 Electricity demand forecasting

Forecasting electricity demand is a very complicated process due to the need to analyze many different factors that have an obvious impact on the achieved values, but also factors that can potentially affect the behavior of consumers. These include, among others, changes related to the self-sufficiency of recipients (own production), changes in weather and other changes in the behavior of the environment, e.g. summer seasons when schools are not working, additional days off (unexpected), matches played, large local or national events .

The forecasting system enabling the analysis of this type of elements should consist of many smaller modules that would be responsible for collecting all data that could help the main module in further estimation. It is worth to initially explore current data (even by reducing their dimensions using PCA - Principal Component Analysis) and together with experts in the field of forecasting find the elements of the process to which the greatest attention should be paid. And only after the proper preparation of data we can try create a tool for estimating electricity demand. Given the possession of historical data used for forecasting, it can be assumed that the best approach will be supervised learning. A large amount of labeled data in high dimensionality time, suggests further resolution of this issue by using recursive neural networks or *Time-lagged Auto Encoder*[2], i.e. a model that receives data with the previous time stamp as input, then reduces their dimension by looking for dependencies in them on the basis of which it will be able to go the next data record. The layer in which data with reduced dimensions are processed is called bottleneck. In the case of forecasting, when the next forecast depends not only on the previous one, but also on external data, it can be concatenated with this additional data. This will help the model estimate correctly. Both models are adapted to handle distributed data at constant intervals. These types of models would have to be local - each of them representing the relationship between the input and forecast for one defined area. In addition, as energy demand changes, data may expire - do not provide reliable information for later estimations. This problem can be solved in two ways:

- by tuning the neural network on new data from time to time, preferably by freezing the weights of the feature extractors, and learning only the predictive layers[3] (with recursive networks) or the decoder (with the autoencoder),
- creating a special coefficient, which will additionally regulate the results at the output of the neural network, transforming them so that they match the real data as much as possible.

The sample research shows that part of such a system can be created with little effort[4].

4.2 Electricity price prediction

Referring to the above example, the ideal situation, for many energy companies dealing in electricity trading is to have solutions that allow to predict electricity prices, create an optimal purchasing portfolio in not only short-term but also long-term. Creating such solutions should take into account anticipated trends at the level not only national but also international, especially in the context of current and future regulations.

[2] C. Wehmeyer, F. Noé, *Time-lagged autoencoders: Deep learning of slow collective variables for molecular kinetics*, The Journal of chemical physics 148.24 (2018): 241703.
[3] Freezing the weights means that we do not change those weights in further learning, reducing the complexity of the task and speeding up the process
[4] K. Amarasinghe, D.L. Marino, M. Manic, *Deep neural networks for energy load forecasting*, 2017 IEEE 26th International Symposium on Industrial Electronics (ISIE). IEEE, 2017.

Analysis of the issue requires the construction of a complex system that will take into account all necessary factors affecting price changes. Predicting trends is only possible if the data shows some kind of temporal dependence. With such complex issues, long-term prediction can be very difficult to achieve. This shows how important it is to develop issues related to chaos theory and at the same time combine the achievements of this field with machine learning[5]. The models responsible for predicting systems that depend on such a number of parameters must be sufficiently sensitive to small changes in input parameters, while maintaining appropriate generalization. These two opposing criteria should be treated with particular caution so that the system works as well as possible.

Current achievements in the field of deep learning, unfortunately, are not adapted to such long-term forecasting of trends with a very wide range. Portfolio optimization, having all the assumed data, can be achieved now through properly prepared systems and evolutionary algorithms[6].

4.3 Customers behavior predition

Anticipating the behavior of power system users in the context of their habits affecting electricity consumption is one of the basic elements of forecasting the area's demand for electricity. However, electricity trading companies also use customer behavior to create customer groups and offer them a set of price offers or products tailored to the needs of these product groups.

Solution proposed by S-V. Oprea, A. Bara[7] shows that it is possible to use a combination of several weaker predictive models so as to estimate the daily electricity consumption based on data from smart meters and weather stations. The aforementioned solution consisted of seven different models, the best of which in previous predictions was chosen to create predictions of energy consumption for the next 24 hours.

[5] N. B. Harikrishnan, N. Nagaraj, *A novel chaos theory inspired neuronal architecture*, 2019 Global Conference for Advancement in Technology (GCAT), IEEE, 2019.
[6] J. Korczak, P. Lipinski, *Evolutionary approach to portfolio optimization*, Proceedings of Workshop on Artificial Intelligence for Financial Time Series Analysis, Porto, 2001.
[7] S-V. Oprea, A. Bara, Machine Learning Algorithms for Short-Term Load Forecast in Residential Buildings Using Smart Meters, Sensors and Big Data Solutions, IEEE Access, Vol. 7, pp: 177874 – 177889, 09.12.2019, https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8928601, dostęp: [05.04.2020].

In the event that the enterprise does not have knowledge of possible dependencies on selected parameters or customers groups, machine learning analysis can be based on clustering methods that allow determining the optimal, in relation to a certain criterion, the number of separate groups of customers. On the basis of the division obtained, similarities between members of such groups can then be analyzed. Based on such research, you can determine what each group needs and what is worth presenting in offers, so that they are best suited to the needs of individual groups[8].

Producers of electricity from seasonal sources are special users of the power system for whom the ability to forecast generation is a very important element, especially in the context of its high variability associated with weather conditions also in conjunction with the creation of scenarios for the sale of produced energy in the most cost-effective conditions. According to data presented by scientists from Germany, models developed for photovoltaics (PV) or wind generation show very good results with good hourly correlation, at the level of 0.992 for wind energy, and low model error (normalized mean square error 0.10). In contrast, electricity demand models and price models need to be refined to obtain results of acceptable quality[9].

One can imagine that in the future forecasting mechanisms will be related with conditions (capabilities and needs) of power networks, but also concluded possible contracts for the provision of flexibility services. Such forward-looking forecasting models should indicate the most profitable behavior for the producer ensuring energy security. Nevertheless, both the level of development of power networks which meet the requirements of the smart grid in connection with the constantly evolving machine learning algorithms, it is very complicated task to create systems that combine the above elements.

The field that shows the greatest possibilities in this type of approach is reinforcement learning, which however, would require the creation of a very accurate simulation of the behavior of the power network with many variable parameters. In addition, the current state of this type of algorithms requires unusually high computing power and neural networks with a

[8] J. Sala, R. Li, M. H. Christensen, *Clustering and classification of energy meter data: A comparison analysis of data from individual homes and the aggregated data from multiple hom*es. *Building Simulation*, Tsinghua University Press, 2019

[9] J. Baumgartner, J. Schmidt, K. Gruber, *Using machine learning to predict renewable electricity generation, electricity demand, and electricity prices from climate data*, Geophysical Research Abstracts, 2019, Vol. 21, p1-1. 1p.

number of parameters counted in tens of millions, whose learning can take up to several to months, during which entire teams analyze their operation and carry out "operations"[10]. The main problem here is the size of the project, which would require a very long and expensive to maintain a research project.

4.4 Analysis of electric car charging impact on the electricity grid

Forecasting mechanisms combined with power network topology in a selected area saturated with distributed energy sources, charging stations for electric cars could effectively support the processes of managing electricity flow in the network, e.g. by performing automatic reconfiguration of the network or launching flexibility sources available in the selected area (along with automatic settlement of transactions carried out). An attempt to solve this problem involves elements of predicting the future, which without proper data and a large simplification of real processes is impossible to achieve at a high level of reliability.

Nevertheless, predictions related to car charging are estimable. In this case, cooperation is necessary between the creators of electric cars, which should ensure that the car is equipped with the necessary technologies for the energy industry. Such cars could send location data to the central system (for safety, similar results should be obtained by giving the location data of the nearest charger, or the most frequented) and personalized for a given car probability that it will be charged in the near future. An estimation of this probability could be achieved by using neural networks, which are called universal function approximators, i.e. a suitable neural network is able to adapt to any function in a mathematical sense. With such data, a graph system that has information about the power network topology in the relationship graph format would be able to predict and correct changes in the load on that network on an ongoing basis. Graph learning algorithms such as graph neural networks or related approaches could help in this task[11].

4.5 Identifying potential locations for illegal electricity consumption

[10] J. Raiman, S. Zhang, C. Dennison, *Neural Network Surgery with Sets*, arXiv preprint arXiv:1912.06719, 2019.
[11] W. Hamilton, L. Rex Ying, J. Leskovec. *Representation learning on graphs: Methods and applications*, arXiv preprint arXiv:1709.05584, 2017.

In this regard, research has already been carried out, described inter alia by A. Ghasemi[12], H. Hao[13] and S. Mandava[14]. There are several approaches which fall into two main categories. One of them requires smart grids, and certainly smart meters with remote access to monitor current changes in energy consumption. What seems important in this category is remote access to data and the possibility of obtaining good quality data. The quality of the data depends largely on the method of obtaining it. For solutions based on PLC, often the interference generated by other devices is so large that the quality level of the data obtained will not always guarantee the high reliability of the models used. The problem of data quality is, however, appropriate for most of the analysis performed, regardless of the technology used to develop the model. In order to compensate for disturbances arising on the power network, in addition to the possibility of using standard processes such as filters with different bandwidth, you can try to use the aforementioned autoencoders with a suitably modified learning method, or recursive neural networks described in the study by K. Antczak[15].

The second category is trying to circumvent the limitation of the lack of smart meters with remote access, operating on already available data from billing systems. Two approaches can be distinguished in this category. The first approach is to create a type of energy consumption template (profiles) for everyone from users and detecting deviations between consecutive days of use, finding collection points potentially suspected of illegal consumption. The second one creates a similar model, however, on the data available on invoices, without the need for continuous hourly access to the meter. The credibility of the second solution depends on the way of invoicing. As of today, the vast majority of invoicing is based on the consumption forecasting system, which means that actual settlements are made in different periods for different groups of customers, not necessarily monthly. Hence, an attempt to use this kind of data to create models that give a high level of reliability may not bring the expected results.

[12] A. Ghasemi, M. Gitizadeh, *Detection of illegal consumers using pattern classification approach combined with Levenberg-Marquardt method in smart grid*, International Journal of Electrical Power & Energy Systems 99, 2018, pp: 363-375.
[13] H. Hao, S. Liu, K. Davis, *Energy Theft Detection Via Artificial Neural Networks*, IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), IEEE, 2018.
[14] S. Mandava, J. Vanishree, V. Ramesh, *Automation of Power Theft Detection Using PNN Classifier*, International Journal of Artificial Intelligence and Mechatronics 3.4, 2014, pp: 118-122.
[15] K. Antczak, *Deep recurrent neural networks for ECG signal denoising*, arXiv preprint arXiv:1807.11551, 2018.

4.6 Use of drones to keep records of grid devices

The whole system of autonomous drone control can be created on the basis of geographical data of the power network, used to determine the path of the vehicle. Appropriate interpretation of the structures to which such drones should fly and identify selected elements can be used by systems analogous to those that arise in autonomous cars. Very fast recognition of objects on film frames is within the range of basic models of neural networks such as, for example, YOLOv3[16] or RetinaNet[17]. Object recognition along with the location of their landmarks gives the drone the opportunity to position itself so that all data needed for the recording can be read from the obtained camera image using a certain type of OCR[18] system. Separately, the creation of each of these systems is not too complicated, but their combination means going through physical barriers, such as, for example, the drone's battery life while operating so many systems and charging stations optimally distributed for the drone, or people who will supervise its operation and replace the batteries when they are empty. Due to such limitations, the introduction of such a solution will require greater human supervision.

4.7 Anticipating problems with the stability of the power grid

The topic of stabilizing the work of the power grid, or the mechanisms of managing the work of this network are not a new topic, because the daily work of the power system requires it. Nevertheless, the characteristics of connected distributed energy resources and customers are changing dynamically. The power system designed for the flow of energy in one direction, from producer to consumer, is undergoing transformation, one of the effects of which is two-way energy flow. These changes occur dynamically, causing that the power grid in many places "does not cope" with stability and quality of supply. Models based on machine learning can be helpful in managing such power networks, as the Portuguese distribution network operator presented in the project. The project focuses on the operation, control and protection of the distribution network from low voltage busbars in substations through the low voltage network to an intelligent meter. It was assumed that the quality of the power grid operation can be

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[16] J. Redmon, A. Farhadi, *Yolov3: An incremental improvement*, arXiv preprint arXiv:1804.02767, 2018.
[17] TY. Lin, et al., *Focal loss for dense object detection*, Proceedings of the IEEE international conference on computer vision, 2017.
[18] S. Stoliński, W. Bieniecki, *Application of OCR systems to processing and digitization of paper documents*, Information Systems in Management VIII, 2011, p: 102.

improved by proactively stopping events related to maintaining the quality of the energy supplied, based on techniques using artificial intelligence algorithms. Based on the thesis that the majority of electrical devices are designed to function properly when powered by permissible voltages, the voltages recorded on the meters were analyzed. Although the conducted research did not give a result at 100% reliability of the results achieved, according to the presented conclusions, management of smart meters is an important part of controlling and monitoring the power grid in order to obtain full flexibility and efficiency of this network in the future[19].

It is for the smart grid network that research is carried out based on the creation of a system that takes into account not only the sensory indications on the analyzed equipment, but also takes into account the results of the inspection of the device. For better agreement between the proposed radial neural network and the inspector, Failure Mode and Effect Analysis is used, i.e. measurable determination of critical points of given systems. Based on this data, the neural network decides whether it is soon possible for a given part of the power grid to fail[20].

5. Final conclusions and recommendations

Scientific institutions, companies or individual units that are able to use surrounding information and data have the ability to aggregate and fully use this information, are already leaders of change.

In order to develop algorithms and approaches in which modern technologies would meet the market demand, apart from digitizing most data, it should be made available (properly prepared and deprived of sensitive data) under open licenses, so that scientists can use them when conducting scientific projects. In addition, it is worth strengthening close cooperation between the scientific community and industry, supporting development projects that promote research for new solutions in contract records, regardless of the level of achievement of the final result. Of course, this involves the risk of not completing the project, but allows those involved in scientific development to conduct experiments that can accelerate this development.

[19] T. M.Vazquez Sanchez, P. Pérez Núñez, J. Díez, J. Fernández-Lopez, Fault detection in low voltage networks with smart meters and machine learning techniques, 25th International Conference on Electricity Distribution, Madrid, 3-6 June 2019, Paper n° 851.

[20] N. Nadai, et al., *Equipment failure prediction based on neural network analysis incorporating maintainers inspection findings*, Annual Reliability and Maintainability Symposium (RAMS), IEEE, 2017.

Regardless of what topic the discussion is going on, usually the basis for success for both sides of this discussion is mutual cooperation, which also means necessary compromises. This is also the case when collecting experience regarding the creation of self-learning algorithms. Because without these experiences it will not be possible to eliminate those places in algorithms that do not bring satisfactory results.

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