

Artificial Intelligence as a Booster of Future Power Systems

Tiago Pinto 

Department of Engineering, University of Trás-os-Montes and Alto Douro and INESC-TEC, UTAD's Pole,
5000-801 Vila Real, Portugal; tiagopinto@utad.pt

1. Introduction

Worldwide power and energy systems are changing significantly. The main driver for the profound transformation of the energy sector is the massive introduction of renewable energy sources [1]. Addressing energy generation sources of variable nature requires rethinking traditional planning, operation, management and transaction approaches that have been used for many years [2]. Moreover, the increasing need for involving consumers as central actors in the power system activities, as a way to capture the potential of consumption flexibility to balance the intermittency from the generation side, is forcing the emergence of new models for demand-side management and demand response [3]. The common trading environment for power transactions is evolving accordingly, becoming more local [4] and with an increased level of automation [5].

The consequent increasing complexity and dynamism of power and energy systems brings out the need for the development of new, advanced solutions able to deal with the novel characteristics of the system. Artificial intelligence, therefore, emerges as a natural resource to provide solutions to the envisaged challenges [6]. The research community has been studying quite broadly how artificial intelligence is used and how it can evolve in the future to deal with all kinds of energy-related problems [7]. Some of the most relevant domains within the scope of artificial intelligence relate to simulation and optimization, as described in [8], and to the application of machine learning models, with special emphasis on probabilistic and stochastic models [9] and deep learning models [10].

In turn, the most common addressed problems are closely connected to the stochastic nature of renewable energy generation [11], in particular solar- and wind-based energy generation forecasting [12]. On the other hand, the consumer and its role in future power and energy systems also play a predominant role in artificial intelligence research. One of the most important points concerns the forecasting of energy consumption [13]. Reaching a solid prediction of future energy consumption enables, in turn, the development of suitable demand-side response models [14], ultimately leading to the creation of intelligent solutions for buildings' energy management [15].

This article collection addresses the role of artificial intelligence as a relevant driver of future power and energy systems. The selected articles address relevant topics in the artificial intelligence domain as enablers of innovative solutions to deal with distinct power system-related problems. One can see that the multidisciplinary nature of the addressed issues is very present among researchers and scholars, who are well aware of the importance and impact that the new power system paradigm brings in various domains, reflecting on the quality of the contributions submitted.

Accordingly, the selected papers cover a wide range of application topics and artificial intelligence technologies, including models to deal with power quality disturbances, generation and power network expansion planning, and the forecasting of consumption, solar- and wind-based renewable generation, and power transactions.

2. A Short Review of the Contributions in This Article Collection

Undoubtedly the most significant trend in artificial intelligence research, and particularly in machine-learning-related development, deep learning is addressed in [16] as the



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basis for the creation of a diagnosis method to identify power quality disturbances. The deep learning model follows an autoencoder architecture to achieve an adaptive pattern characterization based in a set of features resulting from a feature extraction stage.

Deep-learning-based models are also used in [17,18] to address expansion planning problems. In [17], a bi-directional long short-term memory network is applied to forecast the annual peak load of the power system as a means to address the generation expansion planning problem. The power plants lifetime and the carbon cost are considered as relevant factors in the designed problem formulation. In turn, [18] focuses on the problem of transmission network expansion planning, by analyzing load and wind power uncertainties. This goal is achieved through the application of a deep reinforcement learning model, namely a multi-agent double deep Q network. The authors propose the application of the K-means clustering algorithm to create typical profiles of variable wind and load power characteristics. These profiles are then used to formulate the transmission network expansion planning, which is then solved using the proposed deep reinforcement learning model.

The work presented in [19] addresses the problem of electric power transaction amount prediction using a set of different forecasting models. A comparison is performed among the performance of (i) deep learning models, namely gated recurrent unit, long short-term memory network, convolution neural network, and a combination between the last two, and (ii) other traditional models, namely multi-layer perceptron, support vector machine regression, and adaptive network-based fuzzy inference system.

The value of deep learning models in solving forecasting problems is further highlighted in this article collection through their application to power consumption forecasting, namely using American electric power data in [20] and Polish power demand data in [21]. The model proposed in [20] is based on an encoder–decoder architecture using a gated recurrent units recurrent neural network as means to improve the model capability for dealing with time-series data. A temporal attention layer is included to support the model ability of identifying the most important features in data and a Bayesian optimization approach complements the proposed model by searching for the most appropriate combination of hyper-parameters. In turn, [21] proposes an ensemble learning model comprising three main phases: feature generation, prediction, and models' ensemble. The feature generation is performed using a deep multilayer autoencoder. The identified features are then used by three forecasting models, namely a multilayer perceptron, a radial basis function network, and support vector regression model, to reach the actual forecasts. Finally, an ensemble model is used to combine the results from the different forecasting model into a final power demand forecast.

Despite the interest in and relevance of developing suitable load forecast models, arguably the most challenging task regarding energy forecasting is related to renewable energy generation forecasting, due to their intrinsic variable nature resulting from the dependence on weather conditions, such as solar intensity and wind speed and direction. A review on deep learning models to forecast solar-based generation is presented in [22]. This study focuses on the performance achieved by four of the most widely used deep learning models in this problem. These are recurrent neural network, long short-term memory, gated recurrent unit, and hybrid models comprising the combination between convolutional neural networks and long short-term memory networks. The selected deep learning models are compared against conventional machine learning models. The review concludes that long short-term memory models show the best overall performance, while hybrid models are able to outperform standalone models under the condition of having larger volumes of historic data available and at the cost of longer training times.

Long short-term memory models are, in fact, one of the most promising approaches when dealing with time-series data, especially when these contain intrinsic time-related patterns. The work presented in [23] applies a long short-term memory neural network to forecast wind power generation. The forecasting model is combined with a wavelet decomposition model that decomposes the nonstationary time series into multidimensional

components, which are then used to train the long short-term memory neural network in a way to reach an enhanced prediction performance. A long short-term memory network is also used in [24] to learn time dependencies related to the forecast of wind power ramps with the aim of reducing the menace of ramps to the safe operation of the system. The optimized swinging door algorithm is proposed to detect, in a first instance, wind power ramp events. This algorithm also enables extracting results of ramp features. A convolutional neural network is then applied to extract features from the data and to reach correlations between wind power and ramp features, which are used, in the final stage, by the long short-term memory network to reach the final forecasting results. Wind power forecasting is also addressed in [25] as part of a comprehensive system that provides short-term forecasting for multiple purposes. The stochasticity in wind speed forecast is dealt with using probabilistic forecasting, in which uncertainty is measured using an analog ensemble model. The ensemble considers two distinct models, namely a variational Doppler radar analysis system and an observation-based expert system. These are complemented by a specific model that addresses extreme events by merging numerical weather prediction and a fuzzy logic-based model.

3. Conclusions

The papers within this article collection address the field of artificial intelligence in future power systems through a complementary view on several of the most important topics in this domain. The development of innovative artificial intelligence-based models, with a focus on machine learning approaches, especially those based in deep learning architectures, provides a solid array of solutions able to deal with several of the most challenging problems of future power systems. Deep learning models are presented to overcome power quality disturbances, expansion planning approaches for generation, and transmission power network are presented, and innovative solutions for the forecasting of energy resources, such as solar- and wind-based renewable generation, and load and power transactions amount, are proposed.

Subsequently, this article collection provides a broad spectrum of works covering essential and complementary topics related to the role of artificial intelligence as a booster of future power systems. The perspectives presented in this article collection are crucial towards a more comprehensive understanding of the already achieved solutions in this domain but also present themselves as a motivator of the significant efforts that are still required in future research and development.

Conflicts of Interest: The authors declare no conflict of interest.

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