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Artificial intelligence potential in power distribution system planning

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Abstract: The study addresses the application of artificial intelligence (AI), defined as artificial neural networks, in energy distribution. AI is quickly emerging as a valuable tool in decision- making, holding out the promise for systems that can apply, analyse, evaluate and create autonomously. Currently, no published experience exists of applying an AI in network planning on distribution level. The authors seek to address this vacancy and identify' a number of useful applications of AI in electricity distribution. Bloom's framework for human learning is applied to interpret the current status of AI development and potential application in power distribution.

1 Introduction

Network planning is both an art and a science. The art is to take into account planning laws, historical rules, geographic specifics, local demands, future uncertainties and political decision-making. The science is to design and optimise for reliability and costs while making trade-offs between efficiency, quality and capacity. As the science progresses to more advanced algorithms for network planning it struggles to capture the art side. Could an artificial neural network (ANN) assist in electric distribution and grid planning? We draw upon the analogy of human learning to explore the future potential of artificial intelligence (AI) in general. Human learning can be categorised in six stages [1] of increasing complexity and usefulness.

2 Research question

Two research questions are posed and partly answered in this paper. What applications can be identified where ANNs can be applied? What are the drawbacks for an ANN compared to existing algorithms?

3 Method

The method applied consists of: (i) applying Bloom's taxonomy to try to frame the future potential of AI in general, (ii) identify useful applications of neural networks in power distribution, and (iii) using this framework to identify promising neural network applications.

4 Application of neural networks in network planning

To introduce ANNs and familiarise the reader with these network, a brief introduction of the most important definitions and methods is given. To start with an analogy, the brain is a *biological* neural network. A brain is a neural network of interconnected neurons. At its most basic level, a neuron takes one or more inputs and generates an output (i.e. 'fires'). For example, our eyes generate input for the neurons in our brain, which pass this 011 is input to other neurons, until the neurons generate the output to identify the individual letters and then the meaning of the text you are reading.

The AI research community seeks to learn from the human brain and to transform these learnings to develop ANNs. Are inputs transformed in a similar way to outputs? Do ANNs learn in the same way as biological neural networks?

An ANN is defined as a structured hierarchy of artificial neurons. An artificial neuron is a mathematical function. This mathematical function receives input from sensors or other neurons and produces an output. A large number of neurons are able to detect patterns, classify images, recognise speech, play games, suggest searches etcetera.

The current state of the art in ANN research is convolutional neural networks and deep networks. The convolutional neural networks are applied in object recognition and photo classification. The deep networks are applied in games, autonomous driving and medical research.

More broadly, AI and neural networks are a field within machine learning. Machine learning is a field within computer science which aims to let computers learn without explicitly programming the rules.

Now let us turn to the where it might be applied electric distribution. To do so we turn first to how humans learn, for if we understand human learning, we can identify by analogy where an AI might be successfully applied.

4.1 Blooms taxonomy

Human learning is described by Bloom who created a hierarchy of learning steps [1]. The hierarchy describes simple to complex learning tasks (Table 1).

We draw 011 is on this taxonomy to formulate the applications of AI. The first level of Bloom's structuring taxonomy consists of remembering. This is traditionally a strength that computers have, being able to read and write data almost flawlessly. No neutral network would be required.

The second level consists of understanding, meaning the ability to explain ideas and concepts. Neural networks have already demonstrated this ability in speech recognition and image classification. These abilities could be transcribed and used in the collection and creation of information from power distribution networks data. For example, classifying a network state, transformer operation from simple meter and sensor readings. *An important observation at this point is that an ANN does not understand or grasp the idea or concept. In the current state the ANN simply maps the input to the output to obtain a classified or described information. This mapping yields useful mathematical models, but not yet human 'understanding'. The new field of artificial intuition might provide novel methods that yield a capability more similar to understanding.*

Table 1 Bloom's taxonomy of learning

LvL	Activity	Description
6	create	produce new or original work
5	evaluate	justify a stand or decision
4	analyse	draw connections amongst ideas
3	apply	use information 111 is in new situations
2	understand	explain ideas or concepts
1	remember	recall facts and basic concepts

The third level is to apply information in new situations. An application of this activity is to use existing information to test, interpret or validate new input information coming from the network. Neural networks could use this to validate network data or observe the network operation.

The fourth level sees more complexity and requires the ability to draw collect connections between ideas and concepts. This analytical ability can be performed by neural networks as is being shown in virus scanning trading algorithms, and 'intelligent' metering systems. Prediction, comparison and drawing causal relationships are among the capabilities of these systems. These capabilities could be usefully applied in network diagnosis, network planning, preventive maintenance, failure prediction, network attack recognition etcetera.

The fifth level consists of learning to evaluate correctly. The ability to evaluate implies a more complex trade-off between multiple, and sometimes conflicting, objectives. The ability of a neural network to decide, value and judge is currently cutting edge in the research field and also sees the introduction of ethical consideration. In self-driving cars which have to make driving considerations this is most evident. Even though complexity increases, the usefulness increases as well as AI systems could be applied in flow management, asset allocation, attack responses, theft detection and response etcetera.

The sixth step of Bloom's taxonomy would be the ability to produce new and original work. The application of this ability would see network planning, novel instruction development, parameter setting and infrastructure extension proposals – without the need to explicitly programming the earlier mentioned items which currently make it part art and part science. This level is not yet demonstrated or achievable without extensive input from humans.

Table 2 Potential applications of AI in network planning

Bloom's taxonomy	AI task	Application	Development level ANN
create Lvl 6	design develop formulate	network planning develop instructions network parameters investments	not available not available cutting-edge/ research lab
evaluate Lvl 5	decide	flow management assets allocation attack response	cutting-edge/ research lab
	value	hypothesize	cutting-edge/ research lab
	judge	crisis detection theft detection	cutting-edge/ research lab
analyse Lvl 4	predict	preventive maintenance failure prediction	state-of-the-art
	compare	pattern recognition incidence recognition	state-of-the-art
	causality	network diagnosis problem diagnosis	current
apply Lvl 3	validate interpret	validate network data network operation mode	current simple
understand Lvl 2	describe	information collection	simple
	classify	information creation from meters and sensors	simple
remember Lvl 1	define	comparison	not necessary

Mapping of ANNs onto Bloom's taxonomy yields a number of tasks the ANN has to be able to perform. Each successive level is usually more complicated and complex learning task (Table 2).

ANNs might be envisioned to be usefully applied to learning tasks that exist in level 2 to 6 of the taxonomy. We reason that each level is achievable in theory, if not yet available at the highest level.

4.2 *ANN applicability*

The hierarchy yields several useful considerations:

(i) ANNs can already be applied for a number of network applications. The classification, description, interpreting and validating tasks which are relatively simple, compared to current ANN developments.
(ii) Not one. but multiple ANNs would probably be applied, maybe even at the level of individual assets. These would be specialised ANNs (instead of general ANNs) further simplifying the ANN.
(iii) In the first three levels, understand, apply and analyse, the ANN would assist humans. In the levels evaluate and create would an ANN be expected to potentially replace humans.
(iv) A promising approach would be to combine a number of specific, narrowly focussed ANNs with other AI tools. Where the possibility exists for higher stage AI systems to oversee and control lower stage AI systems.

How could a neural network be applied at the highest level, the, create stage, of Bloom? We try to answer this problem by considering a specific application for network planning.

5 Exploring a neural network for network planning

Here we explore the application of a neural network to the highest level of Bloom's taxonomy, thereby adding to the body of knowledge and understanding of what ANN's could assist with.

The problem of network planning can be described as a shortest path problem. The problem is a simple variant of the travelling salesman problem. Hopfield and Tank established the use of neural networks for the travelling salesman problem [2] which generated a lot of interest in Hopfield neural networks for general routing problems. However, interest faded in Hopfield neural networks in the 1990s as other algorithms provided better outcomes in less computational time and as the network tends to get stuck in local minima [3],

Still, at this stage we suggest to apply a HNN to the shortest path problem as the neural network is generalisable has recently been extended to avoid local minima and has found comparable application in network routing applications [4, 5]. Starting from this point we consider some of the advantages and drawbacks.

Computationally finding the shortest path between two points in a grid of $N=n*n$ points is computationally expensive for a neural network. The reason is that 11 times 11 neurons are computed for the input and output. There are N^4 neuron weights and to compute one weight requires $O(n)$ computational steps. In addition, there are normally many iterations to arrive at a solution. In comparison, the state-of-the art algorithms such as Lin and Kernighan require only N^2. Comparing the two methods yields at least two orders of magnitude less computations for the current state-of-the art algorithms. For a lot of nodes this becomes a drawback of the neural network as fast computers and long-run times are required. With computing costs falling rapidly, this drawback is expected to enable a resurgence 111 is in ANN application, even for real-time network operations.

6 Discussions

In theory, a large number of ANNs could replace a sizable amount of all human tasks that contain learning, even the task of planning, network operation, grid decisions and investment decisions. There is 110 is no theoretical limit to the number of cognitive tasks that involve learning that could not be taken over -pointing the way to

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the boon, or the spectre, of humans being relegated to social human-to-human interactions [6], However, the state-of-the art neural network developments are in different fields from the application of electricity distribution. Within the field Hopfield neural networks are identified as most promising, but these developments are mostly in the research stage and not yet commercially available. While there is a large amount of useful applications, there is no human level understanding of ideas and concepts yet. Humans will be combining the science and the art for some time to come.

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