Ensuring accuracy of machine learning in smart grids with stochastic gradient descent algorithm

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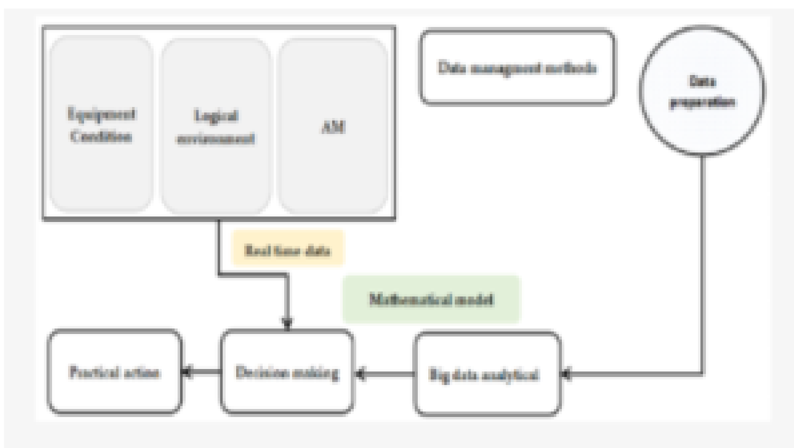
1 Motivation

The rapid advancement of information technology, particularly big data and smart devices, has led to the development of smart grids—electricity networks integrating digital technology to manage energy flow efficiently (IEA, n.d.). A cornerstone of this efficiency is machine learning (ML), particularly neural networks, which mimic human brain processes to optimize system decisions.



As shown in Figure 1, machine learning transforms raw input into practical actions. This case study focuses on backpropagation, a key method enabling neural networks to adjust parameters using algorithms such as stochastic gradient descent (SGD). This process minimizes error and allows the system to autonomously improve performance (Mohsen et al., 2023; GeeksforGeeks, 2025).

Put simply, backpropagation enables neural networks to learn from their mistakes and improve accuracy—essential for stable, self-correcting smart grid operations.

2 Materials.

Smart grids require deep neural networks—models with multiple hidden layers—to perform deep learning. Within these systems, SGD is a preferred algorithm due to its efficiency in handling large datasets and its compatibility with various loss functions (Boopathy et al., 2024). One commonly used loss function is the mean squared error (MSE), defined as: $MSE = \frac{1}{n}\sum_{i=0}^{n}(\$Y\_i \text{ - } \$\hat{Y}_i)^2$, where Y_i is the predicted value, $\hat{Y}_i$ is the actual value, n is the number of data points and MSE is the mean-squared error (EnCoRD, n.d.).

MSE relies on real-world sensor inputs or manual measurements for ground-truth values, and it is commonly used in supervised, unsupervised, and reinforcement learning contexts. Reinforcement learning, especially Deep Q-Learning, is most prevalent in smart grid systems, using trial-and-error and feedback loops (GeeksforGeeks, 2025a).

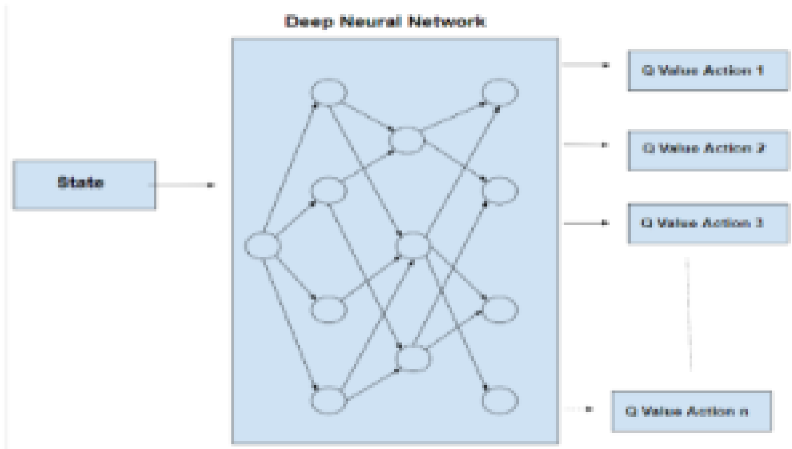


Figure 2 illustrates this cycle, showing how state inputs are transformed into actions using large datasets and neural feedback mechanisms.

3 Method

Backpropagation consists of two phases: a forward pass and a backward pass. In the forward pass, input data (e.g., current readings) are passed through input nodes. These inputs are multiplied by weights and summed at hidden nodes: $a_j=\Sigma(w_i,j*x_i)$.

An activation function like ReLU is applied, producing neuron outputs (o_j). Additionally, a softmax or sigmoid function: $\frac{1}{1+\exp(-a_j)}$, converts values into probabilities, which are then rounded to discrete decisions—e.g., activating or deactivating a circuit component.

The output is compared to actual values using MSE to compute error. During the backward pass, the gradient of this error is calculated and propagated backward through the network. Each weight is updated using the error, learning rate, and neuron outputs. The network iterates until the error falls below a threshold, optimizing accuracy (GeeksforGeeks, 2025).

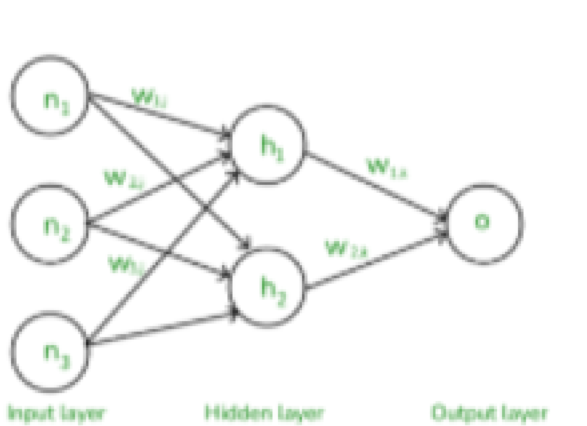


Figure 3 outlines this process, showing the interaction between layers and the feedback loop of error correction.

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