ECONOMIC PREDICTIVE CONTROL FOR SUSTAINABLE ENERGY MANAGEMENT USING MACHINE LEARNING

Kamila Ibragimova[a] *and* ***Azamat Alimukhamedov*** [b]
[a] *Department of Computer Engineering, Tashkent University of Information Technologies, Tashkent, Uzbekistan, komila.ibragimova@inbox.ru*
Mechatronics Research Lab, Turin Polytechnic University in Tashkent, Uzbekistan, azamatalimukhamedov@gmail.com

ABSTRACT

The world's energy sector faces increasing challenges, including rising demand and efficiency needs, changing supply and demand patterns, and the lack of optimal management analysis. These challenges are particularly pronounced in developing countries. Utilizing machine learning (ML) to analyze energy sector data can help address these issues. ML algorithms can examine equipment data, create predictive models, and address sustainability concerns. In smart cities, ML algorithms can autonomously respond to electricity price fluctuations and manage energy consumption. ML-based systems can also assist energy suppliers in adapting to the variability of renewable energy sources. As interest in low-emission energy grows and dependence on oil decreases, the installation capacity of solar PV, wind farms, and marine energy systems is expanding globally. Therefore, artificial intelligence and machine learning are essential for effectively managing energy sector challenges. Microgrid control poses significant challenges that require advanced techniques such as model predictive control (MPC). This paper focuses on energy management in microgrids using MPC and provides an overview of the latest developments in MPC methods for sustainable energy management.

KEY WORDS: energy management, machine learning, predictive modelling, sustainability

INTRODUCTION

In the last few decades, the world’s energy sector is facing growing challenges, such as a demand and efficiency increase, supply and demand pattern change, and the absence of a best management analysis. In developing countries, this challenge is even more intense. In addition, a large number of greenhouse gases is contributing a vital role to the global warming due to the burning of coal, oil and gas are creating a harmful greenhouse effect that is causing global warming and climate change [1]. To combat this climate change, it is necessary to reduce produced greenhouse gases like CO2 emission from fossil fuel and to use alternate renewable energy sources (RES) like solar photovoltaic (PV) panels, wind turbines and water dams to generate electricity with very little cost of operation and green energy environment. Cities implementing green energy need smart grids to integrate both the sources of energy to get uninterrupted power supply and to optimize resource management by the data driven control system. On the other hand, As solar and wind power generation depends on sunshine and wind speed, there can be a shortfall or excess energy generation by RES. Thus, for continuous power supply to load and to avoid voltage and frequency fluctuation, the local onsite micro-grid is integrated into the main power grid called the macro-grid. When RES generates less power, the macro-grid will supply the remaining power and when RES generates excess power, it can sell it to the macrogrid. Excess energy by RES can also be stored in lithium-ion battery, but it is relatively expensive. For this reason, the researchers from energy sector argue that there is a huge need to sustain our natural resources like coal, oil and gas for further energy production [2]. The mentioned global energy and environmental challenges have led city governments to gradually modify their policies, decisions, and strategies towards greener and energy efficient approaches [3]. The efficient use of energy could reduce energy demand, thus increasing monetary savings, reducing greenhouse gas, and improved energy security. A method was developed to quantitatively predict the effect of greening on building energy consumption to support decision makers for implementing urban greening policy in [4]. From the economic and technical challenge point of view, the smooth running of the power system by switching between macrogrid to microgrid is challenging. Weather data must accurately predict renewable energy production. Production of energy must foresee the demand of individual households and aggregated power consumption of a larger region. Overall power production, transmission, distribution and delivery to the consumer have to be more tractable, viable and cost-efficient for all parties like a stakeholder, government regulators, clients and consumers.

ML is prevalent in almost every renewable energy research (e.g., solar, wind, hydrogen, and hybrid) for optimization, design, management, estimation and distribution. The proposed AI algorithms for renewable energy research are complex and expensive. These models need to be simplified and cost-effective. Energy use information improvement with worker banks and other gadgets running constantly should be planned without cooling the energy and cost reserve funds. Energy forecasting and planning are important for different kinds of stakeholders for making the decisions of sustainable future energy development globally. The accuracy of energy demand forecasting models allows a great interest in different applications to avoid unexpected power blackouts as well as reduces the operating costs. ML models like support vector machines, artificial neural network, Gaussian processes, K-nearest neighbor and others overcome the problems of irregularity and complexity in modern energy. Below, we briefly introduce commonly used ML algorithms in energy related industrial applications.

METHODS

Machine learning is a set of techniques that can automatically distinguish patterns in data, and then to predict future data, or to perform other kinds of decision making under uncertainty. There are three main types of ML methods namely supervised learning (predictive), unsupervised learning (descriptive), and reinforcement learning. In these paper, we mainly focus on the first two types of ML algorithms. In the supervised learning methods, the purpose is to discover a mapping from inputs to outputs, given a labeled set of input-output pairs. In the unsupervised learning methods, while only the inputs are given, the purpose is to recognize interesting patterns in the data. Unlike supervised learning, this is a much less distinct problem, as there is no confidence of what patterns to look for, and there is no specific measure of error to use.

Decision Tree Algorithms

Decision tree methods [5] construct a model of decisions made based on actual values of attributes in the data. Decisions fork in tree structures until a prediction decision is made for a given record. Decision trees are trained on data for classification and regression problems. Decision trees are often fast and accurate and a big favorite in machine learning. The most popular decision tree algorithms are Classification and Regression Tree (CART), Chi-squared Automatic Interaction Detection (CHAID), Decision Stump, Conditional Decision Trees.

Bayesian Algorithms

Bayesian methods are those that explicitly apply Bayes' Theorem for problems such as classification and regression [6]. The most popular Bayesian algorithms are Naive Bayes, Gaussian Naive Bayes[7], Multinomial Naive Bayes, Bayesian Belief Network (BBN) and Bayesian Network (BN).

Clustering Algorithms

Clustering, like regression, describes the class of problem and the class of methods. Clustering methods are typically organized by the modeling approaches such as centroid-based and hierarchal. All methods are concerned with using the inherent structures in the data to best organize the data into groups of maximum commonality. The most popular clustering algorithms are: k-Means, k-Medians, Expectation Maximisation (EM) and Hierarchical Clustering

Artificial Neural Network Algorithms

Artificial Neural Networks are models that are inspired by the structure and/or function of biological neural networks [8]. They are a class of pattern matching that are commonly used for regression and classification problems but are really an enormous subfield comprised of hundreds of algorithms and variations for all manner of problem types. Note that I have separated out Deep Learning from neural networks because of the massive growth and popularity in the field. Here we are concerned with the more classical methods. The most popular artificial neural network algorithms are Single Layer Perceptron, Multilayer Perceptrons, Back-Propagation, Stochastic Gradient Descent, Hopfield Network and Radial Basis Function Network (RBFN).

The importance of predictive modeling in different energy source sectors

Renewable energy generation consists of dispatchable (synchronous) power such as hydropower and biomass, and variable (or asynchronous) generation such as wind and solar. While synchronous generation may be added seamlessly to the generation mix, the inclusion of asynchronous generation requires more care. The variable nature of such renewable sources makes the total output of the grid supply unpredictable, and their integration into the system leads to system instabilities. These two issues necessitate, amongst other things, the predictive modeling of variable renewable energy resources as well the use of new methodologies for enhancing system strength.

ML advancement has been building experimental machines to perform different kinds of intelligent behavior in the energy industry. The ML will be the heart of almost each major technological system such as power system cybersecurity, financial markets, payments, nuclear power plants, electrical grids, logistics, manufacturing, building construction and so on. Figure 1 shows the impact of AI on the energy and business sectors [9]. We can see that energy is a very important parameter and that it will play a key role in the world economy in the near future. Expectations are higher for the impact of ML on energy businesses across different industries. The part of the red line in Figure 1 covers the impact of ML technology on different types of business over the next five years. The horizontal axis explicates the "Effect of offerings," and the vertical axis shows the "Effect of processes." The "Effect of Offerings" provides increased opportunities and impact of ML in different sectors (accept or reject as desired), and the "Effect of Processes" is a series of actions or steps taken to achieve a specific goal. Most organizations predict higher impacts on energy information technology (IT), manufacturing and operations, customer oriented activities, and supply chain management. Leaders of industrial companies expect to have a higher impact on the energy, manufacturing, and operation sectors. Besides, the leaders of different industrial companies expect the most significant impact on manufacturing and operations.

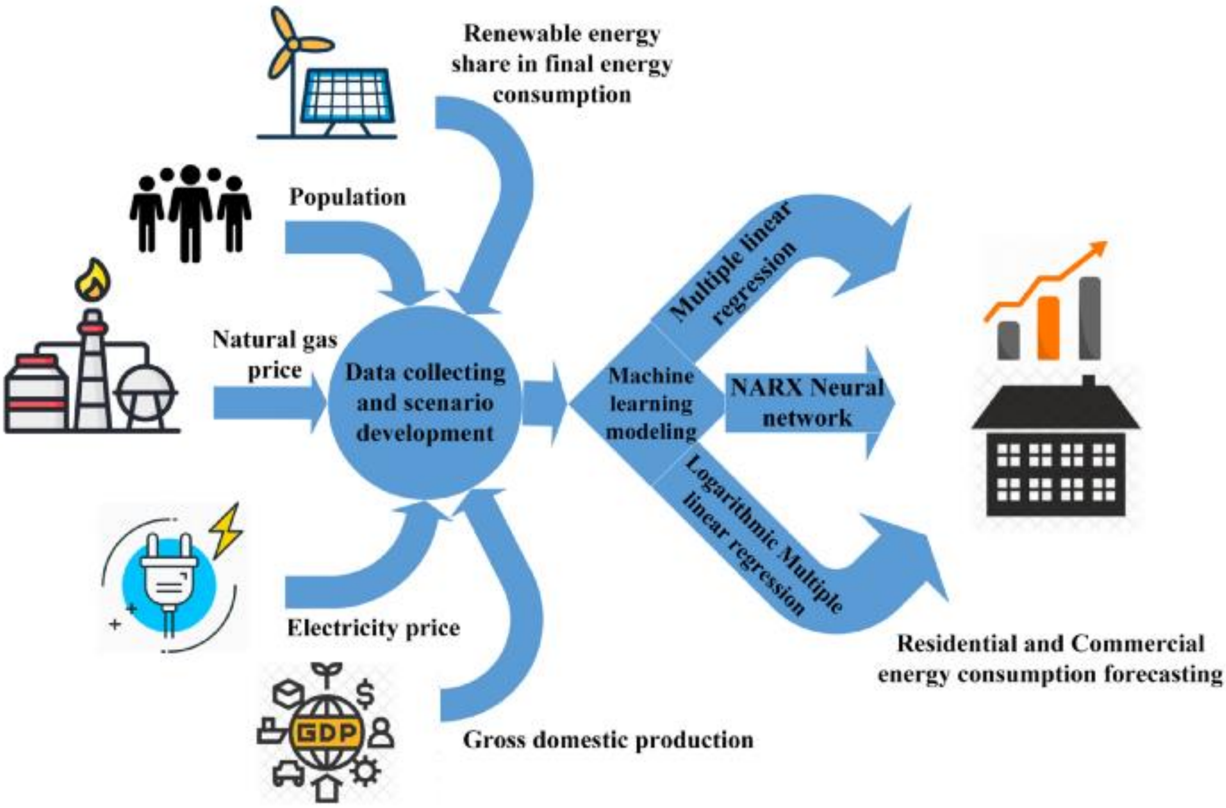

Figure 1. Impact of machine learning on the energy industry.

RESULTS

Modern power system automation mainly covers three technical fields, i.e., maintenance, control, and technical management. The control of the power system aims to achieve good efficiency and quality of the networks. Maintenance objectives can achieve high availability and reliability. A performance involving social and economic benefits is the ultimate objective of technical management. In order to meet the overall needs for reliability, performance and benefits, they need to be explored as a whole and an intelligent maintenance-control-management system developed to meet these requirements. According to the industry report, maintenance costs account for 15% - 40% of total production, and one-third of total production is attributed to incorrect and unnecessary maintenance. It needs time, and therefore an advanced form of predictive maintenance control should be implemented.

The energy management system (EMS) provides a wide variety of control solutions from simple heuristic strategies based on the hysteresis operation mode [10], methods focused on artificial intelligence by the use of fuzzy logic [11], as well as complex control algorithms aimed at optimizing multi-objective functions [12]. Model Predictive Control (MPC) is a control methodology which has been satisfactorily applied to solve complex control problems in the industry and also currently it is widely researched and adopted in the research community. MPC theory is a multivariable control method which is based on an optimization function, so if a suitable model plant is available, MPC theory drives the predicted plant output to the desired reference as close as possible, taking into account the constraints supported by the plant. During the last decade, control engineers have been trying to bridge MPC with ML to overcome difficulties in modeling the system dynamics. We refer [13-14] to reader for applications of MPC based ML algorithms to enhance efficient energy management.

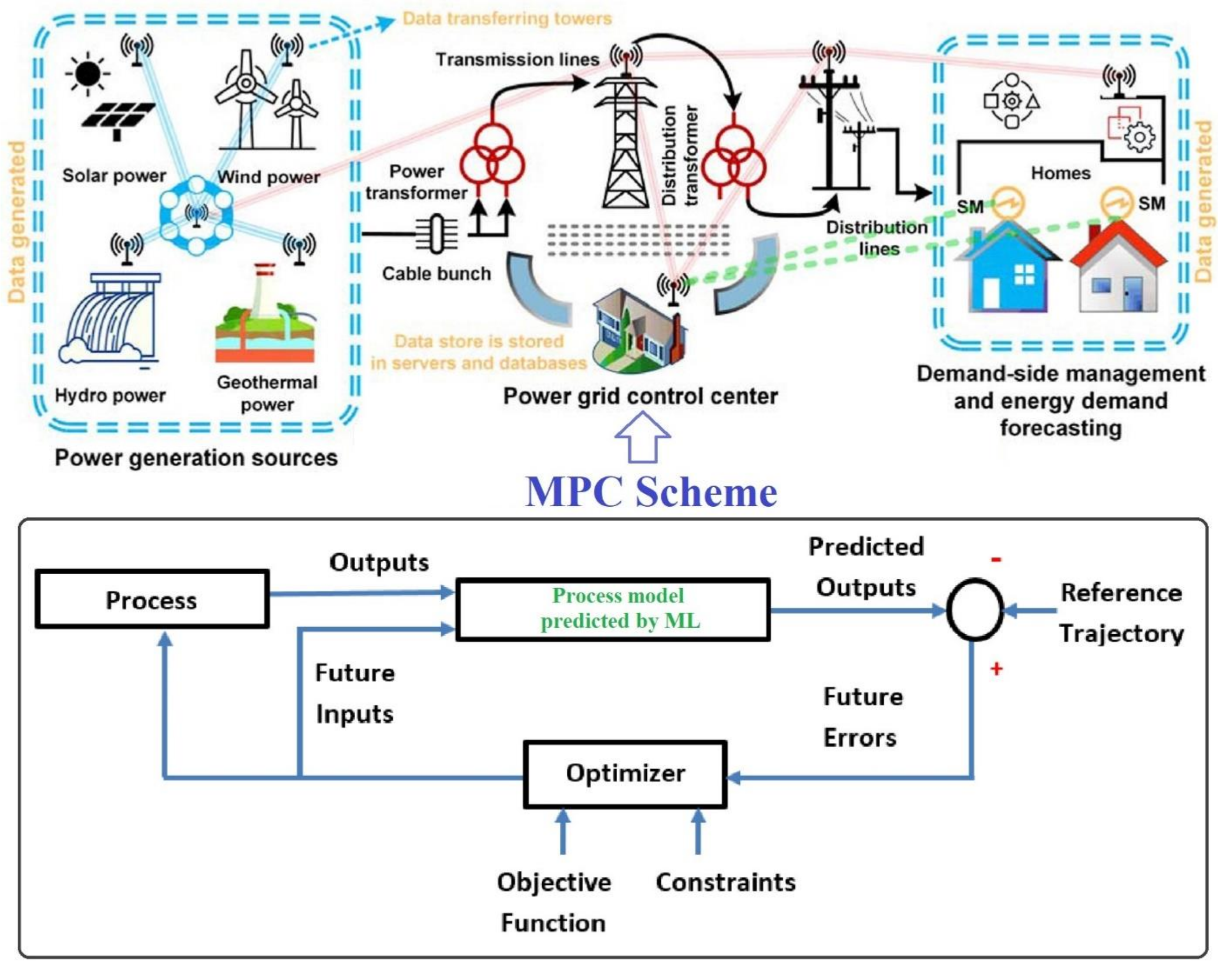

Figure 2. Big data and ML based MPC applications.

The potential of ML has been used for increased power processing and the generation of large data. ML tools extract values from new data and help to control complex energy systems. The interconnection between big data and ML is a daily requirement for an intelligent tool to efficiently optimize and analyze a large number of datasets generated from power systems. Big data and ML tools further enhance planning and decision-making, inspections, condition monitoring, supply chain optimization, and accreditation to improve modern energy systems' efficiency and accuracy. Figure 2 visualizes large data ML interconnection and real-time applications in energy systems. The combination of big data and AI helps to increase the reliability of energy systems (e.g., ensuring the efficient use of renewable resources and storage and improving the management of operations), optimization (increased maintenance and management of assets, effective operations, portfolio and workflow management, etc.), equipment and forecasting efficiency (for example, the forecast of renewable energy using aggregated data such as wind, solar, hydro, geothermal, tidal, etc. and merging it with environmental data), safety and demand management (e.g., helps with outage response and forecasting, predicting the consumption and generation of small customers and producers, respectively) and delighted consumer experience (e.g., enjoy the experience and meet the demands of the consumer load).

CONCLUSION

This research is mainly focused on the applicability of machine learning method in different field of renewable energy source sectors for sustainable development. The studies mentioned above, define different fields where we used machine learning technology for demonstrate the green engineering. In most of the studies the basic approach is to increase the effectiveness without harming the nature. The integration and optimization of renewable sources using ML technologies with the power grid can increase resilience, reliability, the stability of the power system, efficiency, load planning and management. Future work will research further machine learning methods to determine the most suitable method for each field whether its electricity, water, crops analysis and etc

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