SMART BUILDINGS ENERGY SAVINGS WITH GRADIENT BOOSTING ALGORITHM

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In this article, authors pay attention to global tendencies in energy consumption and production specifically shifting to a new energy pattern which is aimed at resource-saving and resource efficiency. This new energy pattern is connected with the industrial internet of things. Specifically, in commercial buildings, the advanced measurement infrastructure is commonly used. It has resulted in the availability of high-frequency interval data. These data can be used in a number of energy efficiency tasks, including the query response, the definition and diagnosis of malfunctions, the optimization of heating, ventilation and air-cooling systems. The arrays of these data enable the use of advanced statistical training models and, therefore, lead to accurate estimates of energy conservation.We underlined the importance of a movement to smart buildings equipped with smart meters, Big Data technologies, special analyzing mechanism – the Gradient Boosting machine. The algorithm of gradient boosting is a powerful tool that has been applied in the fields with intensive data application, including ecology, computer vision, biology. In this article, a method for modeling the baseline energy consumption based on the gradient boosting algorithm is proposed.

Keywords: smart meters, smart buildings, energy production, consumption, GBM, Big Data, renewables, BEMS, BMS, optimization, efficiency, energy saving.

1. Introduction

Nowadays the world is becoming digital, the transition between physical reality and virtual is disappearing. Enterprises are transformed in accordance with changes in the behavior of consumers who always use different gadgets. Artificial intelligence processes large data in giant super-powerful data centers, spawning new classes of software products - voice assistants, "smart" wearable devices, robot-guards. All these possibilities are accompanied by one side effect - humanity consumes more and more electricity.

2. Global tendencies

According to the forecast of International Energy Agency global electric power generation will increase by 63% in the nearest 30 years (picture 1). This trend is caused by rapid economic development of such countries as China, India, Southeast Asia, Middle East etc. Global energy demand will grow by 70% from 2015 to 2040. That is why, there is a new global energy model which implies 4 main tendencies: shifting to renewables sources of energy as additional and more clean types of energy, decentralization of electricity generation, focusing on energy efficiency of buildings and urban infrastructure, mastering the latest technologies like an internet of things or more precisely industrial internet of things.

Based on these tendencies, the world industry of production and distribution of energy is restructuring. In 2016, according to the analytical company IHS Markit, the volume of electricity supplied by photovoltaics rose by 34% in comparison with a year earlier growth which was 32%. The Bloomberg New Energy Finance report, published in 2017, says that the cost of generating electricity using solar cells in Germany, Australia, the United States, Spain, Italy has already been equal to the cost of energy production by burning coal. The rapid growth of a renewables consumption leads to decentralization of industry. Previously, the main energy generators were large corporations and state-owned entities. Now ordinary citizens and private companies install solar panels and wind generators on the roofs of residential buildings and office buildings. In order to implement energy efficiency processes it is important to understand the structure of primary energy consumption and choose the sphere of such innovations.

In accordance with Annual Energy Outlook 2018, the biggest part of global electricity consumption is used for residential needs and slightly less amount of electricity is used for industrial purposes and commercial needs (picture 3). In 2045 there will be quite familiar situation despite some peculiarities: the share of industrial sector is going to be a little bit higher than the share of residential sector; total quantum of consumed electricity is going to be higher in all sectors [1]. The U.S. Department of Energy and UNEP estimates that buildings heating and cooling systems accounts for nearly 18-24% of all energy usage. Besides, they produce 40% of total carbon footprint. At the same time, buildings certified as "green" throw 34% less carbon dioxide, consume 25% less energy, 11% less water [2]. Owners save lots of money and above this receive benefits from the government - many states are struggling for the reduction of greenhouse gas emissions. So, now such technologies are becoming more and more popular.

According to Navigant Research, the global smart buildings market will triple in the next few years. Now it is estimated at a level of 3.6 billion dollars. It is assumed that in eight years the market will reach the volume of $ 10 billion. According to Research & Markets, now the market of building management systems around the world is estimated at $ 6.65 billion. And every year it is growing by 17%. So, in 2023 it will be 19 billion dollars [1]. Changings in the whole energy model and creation of “green” buildings require new intelligent distribution networks which are called “smart grids” that should be bidirectional. Intelligent electrical networks allow users to be disconnected in those moments when they can provide themselves with energy, take the excess energy that they generated, as a payment used before, redistribute it, and so on. This cannot be done with a help of "analog" networks, only on digital ones, equipped with sensors, switches, remote monitoring and automatic intelligent control. The course on energy efficiency in recent years has been taken by many companies around the world. They digitized the infrastructure and converted buildings into "smart" ones. The building energy management systems (BEMS) are in great demand. According to Navigant Research, the market for such analytical software solutions will reach $ 11 billion by 2024, annually growing by 18% since 2015 [3].

3. Some examples of smart buildings

Already there are many examples of the usage of smart technologies. For example, SIBUR is working on the implementation of IoT and a number of other technologies as part of a long-term full-scale digitalization strategy that covers all stages of the chemical company's value chain. The aim of this work is to increase productivity, create the basis for rapid and scalable changes, and provide additional opportunities for the professional development of employees. What is more, "AUCHAN Retail Russia" has launched a project in order to reduce electricity costs by 20% due to the transition to intelligent equipment and new approaches in infrastructure management.

Even larger and more complex example is the construction of a private medical complex Grand Medica in Novokuznetsk. The building is designed from the very beginning so as not to allow wasteful consumption of electricity. The system is really smart and keeps track of all actions in real time. Let's say someone mistakenly turned on the heating more strongly, instead of weakening the air conditioning. This is not such a rare mistake, and as a result, heating and air conditioning work against each other, spending the day-gi companies in vain. The EcoStruxure platform will notify dispatchers of such waste or automatically correct it (depending on which scenario is provided by the user of the platform).

4. Machine learning models applications

4.1. Gradient boosting machine

In modern buildings lots of things are connected to the internet. sensors are installed on all sections of the smart energy infrastructure: on consuming devices (office equipment, kitchen and climate equipment, uninterruptible power supplies, etc.), switchboards, switches, emergency generators and solar batteries, lines power transmission inside the building and beyond. From them, readings can be taken in real time, with a certain periodicity or only when it is necessary.

Anyway, this information is accumulated in the storage centers in the form of "Big Data" These huge arrays of megabytes contain a lot of hidden valuable information, which can be obtained with the help of special analytical tools. If properly dispose of, the energy system of the building will be more economical, manageable, reliable and safe. Speaking about the concrete mathematical mechanism it may be the gradient boosting machine. The gradient boosting machine (GBM) is a powerful machine learning algorithm that is gaining considerable traction in a wide range of data driven applications, such as ecology, computer vision, and biology [3]. The results of implementation of such algorithm show that using the gradient boosting machine model can improve the R-squared prediction accuracy and the CV(RMSE) in more than 80 percent of the cases, when compared to an industry best practice model that is based on piecewise linear regression, and to a random forest algorithm [4], [5], [14]. Let’s describe this algorithm more specifically.

The main principle is that several simple models, called "weakly learning models," should be combined into one iterative scheme for selecting parameters in order to obtain the so-called "strong learner", i.e. models with improved prediction accuracy. The GBM method can be considered as an algorithm for numerical optimization, the purpose of which is to find an additive model that minimizes the loss function. Thus, the GBM algorithm incrementally adds at each step a new decision tree that effectively reduces the loss function. Namely, in the regression model, the algorithm begins with its initialization, which is usually a decision tree minimizing the loss function (RMSE), and then at each step a new decision tree is adjusted to the current residue and added to the previous model to update the residuals. The algorithm continues to work until the maximum number of iterations is reached or the specified accuracy is achieved. Thus, the model can be improved precisely in those parts where it still poorly estimates the residuals [6].

The GBM algorithm will be more efficient if at each iteration the contribution of the added decision tree is considered with the help of some hyper-parameter that can intuitively characterize the learning speed. The idea of the procedure for selecting a hyper-parameter is that a greater number of small steps provides higher accuracy than a smaller number of large steps [11]. The parameter can take a value from 0 to 1, and the smaller it is, the more accurate will be the model. However, the choice of a stronger shrinkage (less) implies a larger number of iterations to achieve convergence, since the value is inversely proportional to the number of iterations.

Another way to improve the accuracy of predicting the GBM algorithm is to add randomization to the estimation process. At each iteration, instead of using a complete set of data, a subset is used to evaluate the decision tree (usually without replacement). However, in order to assess the effect of reducing the number of data points on the quality of model fitting, several subsamples of different dimensions need to be checked. In the GB model, there are four hyper-parameters that are needed to be configured: (1) d the depth of decision trees, which also determines the maximum order of the model; (2) K is the number of iterations, which also corresponds to the number of decision trees; (3) the learning rate, which is usually a small positive value between 0 and 1, the decrease of which leads to a slowing of the evaluation procedure, thus requiring the user to increase K; (4) a piece of data that is used at each iteration step [6], [7]. The most popular method for choosing hyper-parameters is search grid method. This concept is to define a grid of combinations of hyper-parameter values, build a model for each combination, and select the optimal combination using metrics that quantify the performance of the model in terms of predictive accuracy. Obviously, it is not recommended to use the same observations that were used as training data for estimating models for comparing predictive indicators. Therefore, it is necessary to evaluate the accuracy on an independent set of data points. Ideally, the available data should be divided into two samples: the training sample and the test sample. [14]

4.2. What is necessary to create a smart building

The first step is to organize energy consumption accounting. Smart meters will show at what time which parts consume too much and why. What equipment is installed, and which gadgets consume too much and why. Already at this stage, there can be a positive economic effect thanks to identifying the cause of energy over expenditure. Perhaps the printer has broken down and therefore consumes more than it should or is simply needs to be replaced with a more energy efficient one. Perhaps the behavior of employees should be adjusted - they print unnecessary documents, or, for example, someone turns on the heater, and another employee opens the window, because he is hot. Perhaps the heating system spends a lot of electricity, because the doors are open too often and are not separated from the room by a thermal buffer.

Cohesion of the infrastructure gives one more important effect: devices can exchange data and signals, which makes it possible to realize the idea of an "intelligent enterprise". For example, data from meters, both for predictive repairs, and for monitoring the supply chain. Information from them can be received in the ERP (Enterprise Resource Planning) accounting system, which in real time will monitor the speed of business processes and data in other integrated business systems, including external ones [11], [12]. Despite ERP system there is BMS system. The intelligent BMS system independently maintain the air in the building at a certain level of purity and humidity, regulate the temperature in the room, spending a minimum of resources. Monitoring of gas and water pipes are carried out automatically. If there is a gas leak or a water leak, the notification system will immediately trigger, and an appropriate message will be displayed on the dispatcher's monitor. The supply of water and gas can be automatically terminated. The building with the BMS system is more reliable from all points of view, because it reduces the risk of unexpected breakdowns and allows to react promptly to any emergency situation.

5. Conclusion

So, in conclusion we can say that in order to create a better world, it is important to change ideas about energy, its generation, consumption, distribution. We see the creation of a new energy model, which implies efficiency, environmental friendliness, and security. Moreover, there is a requirement in a more intelligent equipment to monitor the reliability of energy supply and to optimize production and consumption. Besides, we need systems that meet the challenges of sustainable development and comply with new standards, rules and codes. Also, there is a necessity in an infrastructure that makes it easy to introduce electrical components and systems, protects people and property from cyberattacks. We need a new, holistic approach to managing electricity. GBM machinery algorithm allows to realize smart buildings mechanism via building a decision tree with high accuracy. Already there are lots of successful examples which were mentioned in this paper. So, smart buildings are the step into the future.

References

[1] EIA Conti J. J. et al. Annual energy outlook 2018 //US Energy Information Administration. – 2018.
[2] IEA Statistics I. E. A. Electricity information 2012 //International Energy Agency. – 2012.
C.~W. Gelling, The Smart Grid: Enabling energy efficiency and demand response. The Fairmont Press Inc., 2009.

[3] Hong W.C., Intelligent Energy Demand Forecasting, Springer Verlag, London, 2013.

[4] Breiman L., Bagging predictors, Mach. Learn. 24 (2), 123–140, 1996.

[5] Friedman J.H., Stochastic gradient boosting, Comp. Stat. Data Anal. 38 (4), 367–378, 2002.

[6] Kuhn M., Johnson K., Applied Predictive Modeling, Springer, New York, 2013.

[7] Shchetinin E.Yu., Lyubin P., Fast two-dimensional smoothing with discrete cosine transform, Springer Communications in Computer and Information Science (CCIS), 678, 646-656. Springer, Berlin, 2016.

[9] Geurts P., Ernst D., Wehenkel L., Extremely randomized trees, Mach. Learn. 63(1), 3–42, 2006.

[10] Srivastav A., Tewari A., Dong B., Baseline building energy modeling and localized uncertainty quantification using Gaussian mixture models, Energy Build. 65, 438–447, 2013.

[11] Zhao H.X., Magoulès F., A review on the prediction of building energy consumption, Renew. Sustain. Energy Rev. 16(6),3586–3592, 2012.

[12] Heo Y., Zavala V.M., Gaussian process modeling for measurement and verification of building energy savings, Energy Build. 53, 7–18, 2012.

[13] Price S., Mahone A., Schlag N., Suyeyasu D., Time dependent valuation of energy for developing building efficiency standards, in: Report Prepared for the California Energy Commission, 2011.

[14] Shchetinin E.Yu., Cluster-based energy consumption forecasting in smart grids, Springer Communications in Computer and Information Science (CCIS), 919, 446-456. Springer, Berlin, 2018.