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A SYSTEMATIC LITERATURE REVIEW ON PREDICTION MODELS IN MICROGRIDS

ATIMAD EL KHAOUAT[1] [0000-0001-6170-1060], LAILA BENHLIMA[2] [0000-0002-0680-5470]

[1]PhD student, Mohammed V University in Rabat, Mohammadia School of Engineers, Department of computer science, Morocco
[2] PhD, Mohammed V University in Rabat, Mohammadia School of Engineers, Department of computer science, Morocco
E-mail: [1]atimadelkhaouat@research.emi.ac.ma,[2]benhlima@emi.ac.ma

ABSTRACT

Microgrids (MGs) constitute the new generation of electrical networks; they are more effective, reliable, scalable and allow simultaneous exchange of energy and data in the network. Prediction is one of the tools that contribute to the development and improvement of MGs because it is used for decision making since, promotes control systems, energy management and so on.

In recent years researchers have produced many prediction studies in MGs using different artificial intelligence prediction methods and techniques they deem appropriate to handle with the prediction problems they are working on. We are interested in this paper to analyse those studies as a Systematic Literature Review (SLR) in order to draw the state of the art of existing prediction solutions in MGs, keep up to date with latest used techniques and evaluate if those solutions are in line with the development of Information and Communication Technologies (ICT) especially big data technology.

Keywords: *Prediction, artificial intelligence, algorithms, machine learning, MGs, SLR.*

1. INTRODUCTION

In order to simplify the understanding of the context of our paper for all scientific communities, the introduction will be started with a simple description of MGs and their main components.

A MG is a distributed electric power system that can autonomously coordinate local generations and demands in a dynamic manner. It is based on information and communication technologies with local sources of energy production, mainly renewable. It is mostly attached to the main grid but it is able to work in islanded mode.

This kind of electricity network can operate connected or isolated to the main network. There are many existing categories of projects implementing MGs such as: commercial, artisanal or industrial areas, University campus, isolated areas, military camps or hospitals…

As shown in Fig 1, MG's architecture contains five main components:

- ✓ Cogeneration: energy production resources (renewable and fossil).
- ✓ Storage: batteries for energy storage
- ✓ Electrical transformer: electrical device which transfers energy from MG to distribution network without any direct electrical connection and with the help of mutual induction between two windings
- ✓ Load: buildings, electric vehicles…
- ✓ Control center: is the intelligent core of MG, based on information and communication technologies. It ensures control of the MG, data storage, data management and analytics… Generally prediction models are trained in this component.

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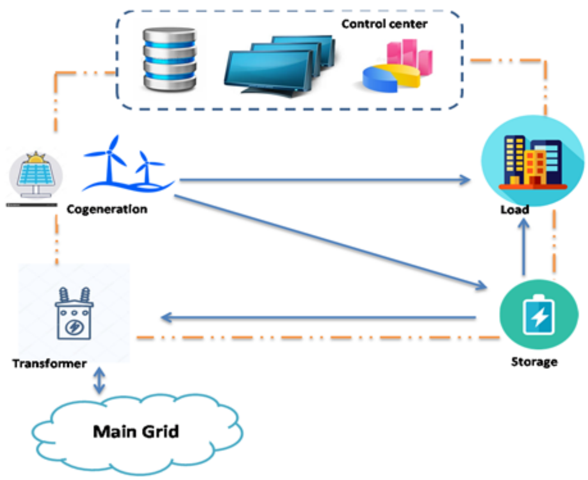

Figure 1: Microgrid's Main Components

In recent years, the development of MGs is benefiting from the emergence of Internet Of Things (IoT) technologies which allow them to become smarter thanks to different intelligent devices installed all over the network such as smart meters, intelligent software applications, smartphones and so on [1]. Those devices generate precious data for scientists because they exploit them to develop prediction solutions, which are used for decision making, promoting the integration of renewable resources for energy production, energy management, control of MGs, energy planning…

To well extract knowledge from data generated in MGs, prediction solutions must be based on reliable algorithms and appropriate techniques. It is something that depends on prediction objective, because MG prediction solutions are proposed for different goals such as prediction of energy consumption, energy production level, renewable energy forecasting and so on. So the challenge facing researchers is to develop the more adequate solution for each specific issue they are working on.

In our knowledge, there is no SLR on prediction in MGs. Such a study is of high interest, because since 2010, there were many proposed works dealing with this topic, which have to be identified, quantified and analyzed to provide a global view of the state of the art of prediction solutions in MGs. Our motivation to conduct this work has been strengthened mainly for three reasons:

- ✓ Institute the state of the art of prediction studies in MGs, this include used algorithms and prediction techniques, goals of those solutions, inputs and outputs of forecasting models, performances evaluation methods…
- ✓ Analyse those studies especially the implementation process of prediction models.
- ✓ Evaluate if those studies are in line with the development of intelligence in MGs and will respond always to their future needs of decision making.

To conduct this SLR we have adopted a process based on a Systematic Review guide dedicated to software engineering [2] which will be described in the second section of this paper.

The rest of this paper is organized as follow. The review process is detailed in the second section including planning the review, research strategy and papers classification. Syntheses are presented in the third section including general analysis, detailed analysis and discussion. Then, finally a conclusion is drawn in the fourth section.

2. PROCESS REVIEW:

This SLR adopts the methodology defined by Kelee university and university of Durham [2] in order to obtain a meaningful research results. It consists of two main phases, which are:

- ✓ Planning the review
- ✓ Conducting the review

The accomplishment of each phase requires the respect of some steps. Figure 2 presents the followed research methodology to produce this SLR.

The first phase is composed of two steps which are:

- ✓ Research motivation: consist of explaining the goal and the need of our SLR
- ✓ Problem formulation: in this step research questions are specified

The second phase of SLR methodology consists of five steps which are:

- ✓ Search terms: identifying strings which will be used to lead the research of resources that address the object of our SLR. These terms are basically derived from research questions.
- ✓ Search resources: identifying resources providing papers and studies which are in relation with the object of our SLR. They include digital libraries, specific journals, conference papers and proceedings.
- ✓ Study selection criteria: determining inclusion and exclusion criteria that will be

adopted to select studies which will be analyzed in the next phase of SLR approach.
- ✓ Data extraction strategy: studies classification to better conduct the review. In this SLR, analyzed studies are classified regarding research questions identified in the problem formulation step.
- ✓ Synthesis of extracted data: Summarizing the results of including studies.

In the next, we detail the steps we conducted in each phase.

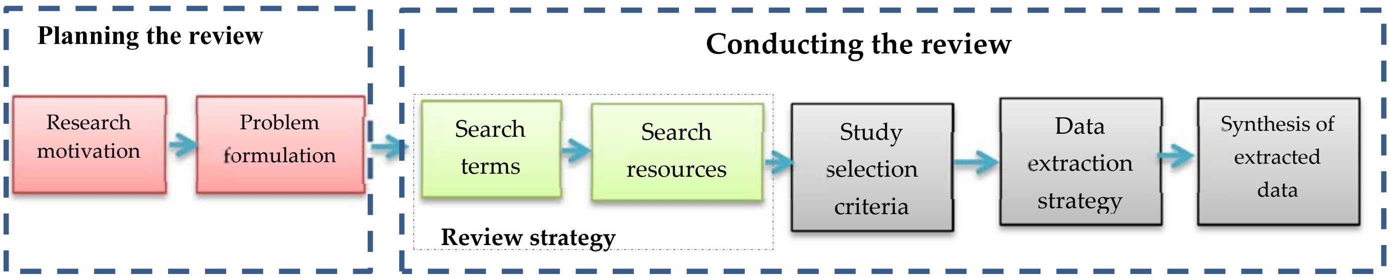

Figure 2: Systematic Literature Review Followed Steps

2.1. Process review

Considering the research motivation highlighted in the introduction of this SLR, the research problem is formulated through the six following questions that will be addressed in this paper:

- ✓ RQ1: what are the inputs/outputs of prediction solutions in MGs?
- ✓ RQ 2: Which classes of algorithms are used for prediction in MGs?
- ✓ RQ3: Which techniques are used for producing prediction models in MGs?
- ✓ RQ4: What are the architecture types in which, prediction solutions in MGs are implemented (centralized, distributed or hybrid)?
- ✓ RQ5: Is the prediction based on big data technologies?
- ✓ RQ6: For the solutions evaluation, which technique, simulation tool, and type of dataset are used?

2.2. Research strategies:

To make the research strategy more rigorous, primary studies related to research questions have been stored and documented in a SLR studies classification file. In this later rejected studies are marked with different colors according to exclusion reason.

The process of elaboration of search terms and sources is presented in the two following parts of this section.

2.2.1 Search terms

To construct search terms, the process presented in table 1 was followed.

Table 1: Steps Of Constructing Search Terms

Step	Action
1	Forming initial terms from search questions.
2	Altering spelling and using synonyms of initial terms.
3	Boolean "OR" was used to incorporate search terms and their synonyms
4	Boolean "AND" was used to link different terms

The following list constitutes a part of the search terms chosen during the construction process in our SLR:

- ✓ Prediction in MG
- ✓ Prediction models in MG
- ✓ Prediction algorithms in MG
- ✓ Energy prediction in MG
- ✓ Energy consumption prediction in MG
- ✓ Energy production prediction in MG
- ✓ Forecasting Models in MG
- ✓ Prediction studies in MG
- ✓ Prediction based on parallelism in MG
- ✓ Machine learning algorithms used in prediction in MG
- ✓ Prediction architecture used in MG
- ✓ Big data analysis in MG
- ✓ Prediction in MG based on big data
- ✓ …

2.2.2. Search sources

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For searching the studies to be analyzed in the field of prediction in MGs, digital libraries listed in table 2 were used. The references of all studies found are stored in the file mentioned above.

Table 2: Search Sources

Digital Library
IEEE Xplore
ACM Digital Library
Elsevier
Springer
Trans Tech Publications
Wiley Online Library

More than 70 papers were found in the initial research stage but only relevant papers were selected based on inclusion/exclusion criteria defined in the next section.

To decide which studies will be included in this SLR, resulting papers in the initial research stage were vetted and evaluated based on inclusion and exclusion criteria listed below:

- ✓ Inclusion criteria
  - o Prediction is applied in MGs.
  - o Prediction process is detailed in the paper especially the used algorithms.
- ✓ Exclusion criteria:
  - o Redundant papers.
  - o Prediction applied on smart grid or traditional grid.
  - o Papers not in relation with research questions.
  - o Studies using just prediction results for another objective like optimization, planning or predictive control…
  - o Review studies, since only primary studies can be analysed on SLR.

2.3. Classification of papers (Data extraction)

To extract data, both authors of this paper have contributed in classifying selected studies based on the most relevant dimensions which are:

- ✓ Paper type: journal, conference papers, proceedings or book chapter;
- ✓ Publication year;
- ✓ Publisher: The name of publisher;
- ✓ Prediction goal: The purpose for what the solution is created;
- ✓ Category of algorithms used in the prediction solution: prediction models overview
- ✓ Category of techniques used in the prediction solution: techniques refer to supervised or unsupervised learning, offline or online learning, parallel or serial computing;
- ✓ Type of architecture in which the solution is implemented: centralized, decentralized or hybrid architecture.

3. SYNTHESIS

This section summarizes the results of included studies through descriptive synthesis with a quantitative summary. Figure 3 shows the whole process of obtaining the analyzed papers.

76 papers were found initially, 9 papers were eliminated after reading title and abstract. Then, 2 redundant papers were removed leaving 65 papers for examination according selection criteria.

The last evaluation resulted in 37 relevant papers which are analysed in this SLR.

Figure 5 shows different types of analysed studies and figure 4 presents their distribution over years.

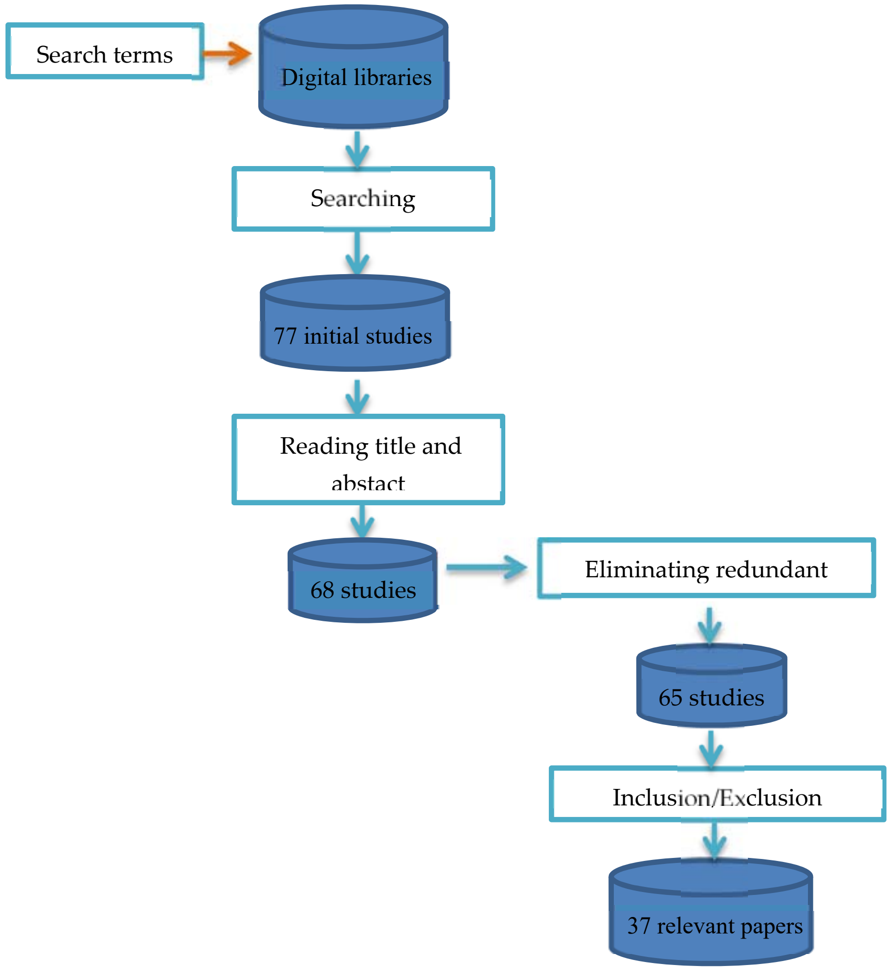

Figure 3: Process Of Selecting Analyzed Papers

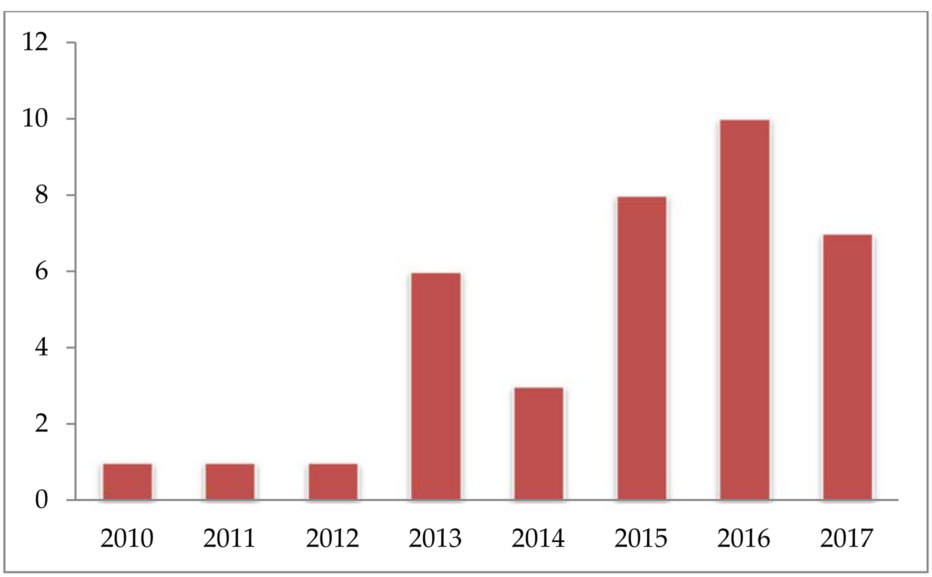

Figure 4: Papers Distribution All Over Years

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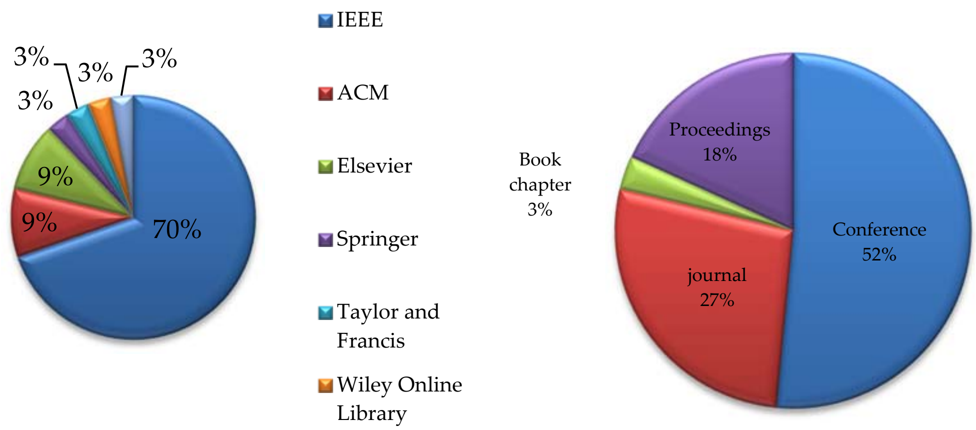

Figure 5: Types And Sources Of Papers

4. ANALYSIS

In this section a deep analysis of selected papers will be proposed regarding research questions presented below in order to resume the state of the art of prediction solutions in MGs.

4.1. Prediction goal:

RQ1: what are the inputs/outputs of the prediction solutions in MG?

Each prediction solution in MGs has a goal in order to deal with specific problem. Analysis done through this SLR shows that they are mainly 4 goals of prediction in MGs which are:

- ✓ Energy management and control;
- ✓ Demand response management, load forecasting and consumption prediction;
- ✓ Renewable energy prediction;
- ✓ Consumption behaviour modelling.

Each prediction model uses inputs to predict output which address one of the goals listed previously. The majority of studies which have explicitly given the inputs of their models are predicting renewable energy or load in MGs and they are listed in table 1. As shown in the same table renewable energy forecasting is always based on meteorological data whereas, load prediction is mainly based on historical load data.

Table 3: Inputs/Outputs Of Prediction Models

Inputs	Output	Reference
• Load data	Short term load forecasting	[3]
• Temperature • Relative humidity • Due point • Sky coverage	Global horizon irradiance	[6]
• Solar irradiance • PV power generation • Ambient temperature • PV module temperature • Humidity atmospheric pressure • Wind speed • Wind direction	Photovoltaic (PV) power generation	[7]
• Historical weather • Historical PV generation • Current forecasted weather	Solar power prediction	[9]
• Hourly irradiance data	Solar irradiance behaviour	[10]

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• Daily time • Maximum temperature • Moisture • Sunshine duration • Wind speed • Irradiance	Solar irradiance	[11]
• Forecasted solar irradiance • Number of solar modules • Number of wind generators • Connection configuration	Power prediction	[11]
• Solar irradiance • Meteorological data	Very short term PV forecast	[14]
• Lagged load • Meteorological data • Time data	Load forecast	[15]
• Meteorological data	Irradiance prediction	[16]
• Demand of the previous day	Electric load prediction	[17]
• Historical load data • Temperature	Very short term load forecasting	[18]
• Solar radiation • Air temperature • Cloud cover	Online short term PV production forecasting	[20]
• demand profiles	Energy usage data	[30]
• Wind speed data	Wind speed signal	[32]
• Real load data	Short term load forecasting	[34]
• Time • Temperature dew point • Humidity • Sea level pressure • Wind speed • Thunderstorm coding • Weekday or weekend tag	Short term load forecasting	[35]

4.2. Prediction models:

RQ 2: Which prediction algorithms are used for prediction in MGs?

There are many algorithms used in prediction solutions in MGs. We have classified them in 7 categories which are: Artificial Neural Networks (ANN), Support Vector Machine (SVM/SVR), Fuzzy logic systems, Reinforcement learning and Markov chain. The class « others » contains the other algorithms used. The papers distribution by prediction algorithm type is given in the next and is summarized in Figure 10.

This section presents briefly each type of classified algorithms and how they are exploited by analysed papers in this SLR.

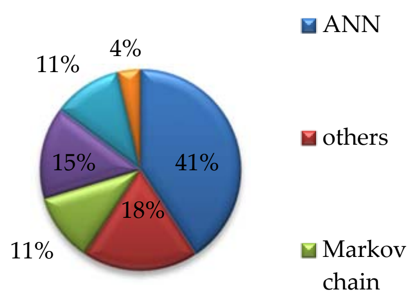

Figure 6: Algorithms Distribution

4.2.1. Artificial Neural Networks

Artificial Neural Networks are set of algorithms which are modelled based on human brain operation [51]. Basically, ANNs are constructed from layers and each layer is made up of interconnected neurons which contain an activation function. The input layer contains patterns which are presented to the network. This layer communicates with one or more hidden layers through weighted connections. The output layer is linked to the hidden layers where the answer is the output of the network.

ANN is the most used algorithm for prediction solutions in MGs, either in a simple form or incorporated with other algorithms or optimization functions. Those solutions are categorized into three types of ANN models: basic ANN, recurrent neural networks and deep neural networks. Table 3 lists the analyzed studies based on ANN.

Table 4: Studies Based On ANN Prediction Models

Prediction model	References
ANN incorporated with evolutionary algorithm	[3]
Recurrent neural networks	[7]
Deep Neural Network	[12]
Back propagation neural networks	[12], [18]
ANN for pattern recognition	[21]
Self-Recurrent Wavelet Neural Networks	[23]
Multiperiod Artificial beecolony incorporated with Markov Chain and Linear regression	[32]
multiple classifier system for prediction based on ANN	[35]
Simple ANN	[5], [15], [20]

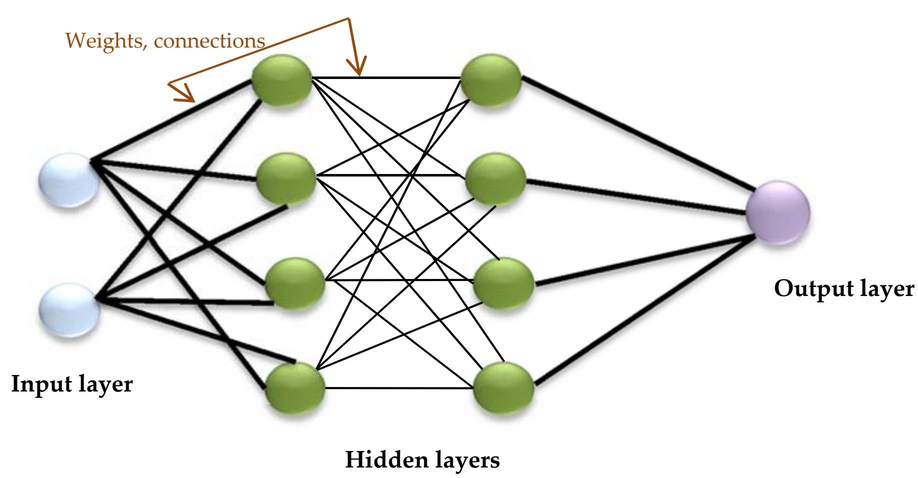

Figure 7: ANN Structure

✓ **Basic ANN:**

We denote by this category a set of prediction models which are based on basic concept of ANN such [5] where the prediction solution is based on simple ANN which is trained using levenberg-Marquardt algorithm with one input layer, two hidden layers and one output layer. In this model input and hidden layers use sigmoid functions as a transfer function whereas, softmax function is used as transfer function of the output layer. Concerning the stopping criterion of the model, the study has limited the number of iterations to 1000 while evaluating the value of the error MSE. The levenberg-Marquardt algorithm is also used in [20] to train the simple

ANN [20], where the network is configured as two-layers feed-forward network with sigmoid hidden and linear output neurons.

The prediction model proposed in [15] is based on Multiple Layer Perceptron MLP with one hidden layer. [3] uses ANN with one hidden layer and the validation error is considered as the objective function of the whole prediction model proposed in that work. MLP is also employed in [21] respecting the following configuration: Bayesian Backpropagation Regulation learning function and the sum squared error as the performance function.

[35] presents a multiple classifier system combined with Multiple Layer Perceptron Neural Network (MLPNN) or Radial Basis Function Neural Network (RBFNN), but this paper doesn't give additional details about the implementation of the two types of ANN used in the prediction solution.

In the model proposed in [32] two ANNs are used for prediction: ANN-1 is applied for the primary prediction which is fed with other features as input variables to the second ANN (ANN-2). Multiple Layer Perceptron (MLP) is used for ANN-1 that includes an input layer, a hidden layer and an output layer. The MLP is used also to train ANN-2 but no details about the number of layers are given in [32].

✓ **Recurrent neural networks (RNN):**

Recurrent neural networks are used especially to make use of sequential information. They are designed to recognize patterns in sequences of data (text, genomes, handwriting…). In [7], RNN with three layers, sigmoid activation function is trained in the series parallel model. The criterion to train the network is to minimize the mean squared error MSE. [23] is based on the (Self Recurrent Wavelet Neural Network) SRWNN is trained as a feed forward network with four layers. The activation function used in this model is a wavelet function.

✓ **Deep neural networks:**

The deep neural networks presented in [12] combines auto-encoders (AEs), Back propagation (BP) algorithm and genetic algorithm for optimization of learning rate of each AE and the number of neurons of each layer. An auto-encoder is an unsupervised ANN which is trained to try to copy its input to its output. The prediction approach in this study is composed of two main processes which are: the pre-training process and the fine-tuning process. In the pre-training process, three stacked AEs which consist of one visible layer, one hidden layer, and one output layer form a neural network. In the fine-tuning process, one more layer is added to the end of the neural network and the BP algorithm is applied to obtain more appropriate initial weights of the whole network. The BP algorithm is also used in [18], with one input layer, one hidden layer and one output layer.

4.2.2. Support Vector Machine/ Support Vector Regression

Support Vector Machine (SVM) is a supervised machine learning algorithm which is used in classification and regression prediction problem. The purpose of this algorithm is to find an hyperplane which divides a given space into a number of classes. Figure 7 shows an hyperplane example of two classes. The main concepts in this kind of algorithms are:

- ✓ Support vectors: data points nearest to the Hyperplane.
- ✓ Hyperplane: line that linearly separates and classifies a set of data in the case of linear problems
- ✓ Margin: distance between the hyperplane and the nearest data point
- ✓ Kernel: in the case of non-linear problems, support vector machine can't separate a data set into classes. Thus, to handle with non-linearity, SVM refer to a method which uses the kernel trick. There are many existing types of kernel functions in literature such as polynomial kernels, radial basis kernels…

Among analyzed studies for MGs prediction, only three solutions are based on SVM/SVR as presented in table 4.

The model presented in [16] is based on Support Vector Regression (SVR) for non-linear problem. It uses a function called E-insensitive loss function (it is a loss function that ignores errors that are within a certain distance of the true value) and then optimize the parameters of this function by using Lagrange multiplier techniques. SVR is also used in the prediction solution presented in [19], the goal of SVR model in this paper is to seek the optimal function to fit a sample data. Structural risk minimization principle is used to determine the various coefficients of the prediction function where the kernel function is symmetric function satisfying Mercer condition.

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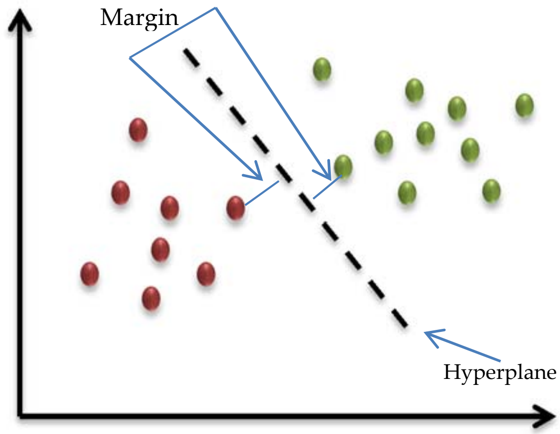

Figure 8: Linear SVM Principle

Table 5: Studies Based On SVR/SVM

Prediction model	References
Simple SVM	[11]
SVR with Grey Theory models	[16]
SVR and empirical mode decomposition	[19]

4.2.3. Fuzzy logic systems:

This concept was born by the introduction of fuzzy sets by Lofti A. Zadeh in 1965. It is a logic which is used to describe fuzziness. The main components of the architecture of fuzzy logic systems are: Fuzzifier, Defuzzifier, Inference and Rules [43]. .

- ✓ Rules: Contains the rules which are used for the operation process. Among those rules, we can find fuzzy rules which are written as "If situation Then conclusion". The situation, called rule premise or antecedent, is defined as a combination of relations such as" x is A" for each component of the input vector. The conclusion part is called consequence or conclusion.
- ✓ Fuzzifier: It is used to convert crisp inputs (exact inputs) into fuzzy sets.
- ✓ Inference: Performs approximate reasoning by deciding which rule will be fired according to the input.
- ✓ Defuzzifier: Based on inference, it converts the fuzzy sets obtained into crisp outputs.

Takagi and Sugeno Fuzzy logic model is the most used fuzzy logic system in analyzed prediction models, as shown in table 5.

The prediction model presented in [8] is based on Interval type-2 Takagi-Sugeno fuzzy logic systems (IT2 FLS) which are fuzzy systems in which type-2 fuzzy sets are used to determine the activation degree of each rule in a Takagi-Sugeno model. This model provides a range output and it has a type reducer and a Defuzzifier to transform the type-2 fuzzy output into a single output. This work has implemented the model using singleton fuzzification, the t-norm product and Gaussian type-2 fuzzy sets with uncertainty in the variance. [29] and [17] are also based on IT2 FLS. The similarity between these two studies is that they both use fuzzy clustering for determining the premise parameters and Takagi & Sugeno method based on least squares for determining consequence parameters.

Adaptive Neuro-Fuzzy Inference System is the fuzzy logic system used in [34], the prediction model consists of the combination of ANN and the linguistic expression function of fuzzy Inference. The architecture of the ANN contains 4 layers. The first layer is composed of adaptive nodes which are described by node function. This function depends on the node's input, linguistic label associated with the node and the membership function of the input to the linguistic label.

Table 6: Studies Based On Fuzzy Logic Systems

Prediction model	References
New interval prediction based type-2 Takagi-Sugeno Fuzzy logic system	[8]
Fuzzy modeling	[29]
Adaptive Neuro-fuzzy inference system	[34]
Stable Takagi & Sugeno fuzzy model	[17]
Fuzzy system Sugeno type used as reward function for the reinforcement learning prediction model	[49]

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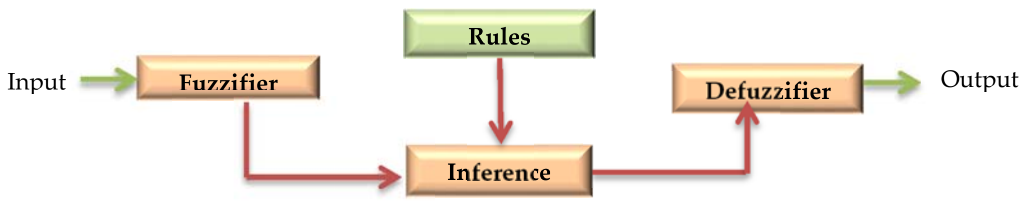

Figure 9: Fuzzy Logic Systems Components

4.2.4. Reinforcement learning

It is an area of machine learning inspired from psychology [44] which is concerned with how agents ought to take action in an environment so as to maximize some notion of cumulative reward. It is used mainly in robot control, games, telecommunication… Recently, this algorithm is more and more applied to predict energy either in smart grids or MGs.

Figure 10: Reinforcement Learning

Among analyzed studies, just three are based on reinforcement learning.

The reinforcement learning model used in [27] is based on Q learning algorithm. The same algorithm is used in [49] and Sugeno fuzzy logic system is used to model the reward.

4.2.5. Markov chain

It is a stochastic model based on probability [45] used to statistically model random processes such as text generation, financial modelling… It is applied in many prediction problems. Analyzed studies based on Markov chain are presented in table 6.

Table7: Studies Based On Markov Chain

Prediction model	References
Real time Markov chain model	[6]
Markov chain	[32]
Markov chain and	[33]

Bayesian networks	

4.2.6. Other used algorithms

There are additional algorithms used for prediction in MG which are:

- ✓ Regression trees: this kind of algorithms is not very used for prediction in MG, among selected studies of this SLR, only the forecasting model proposed in [9] is based on regression trees.
- ✓ Chase algorithms: basically used in database theory to test the implication of data dependencies in the database systems [46]. Mohammad H. Hajiesmaili et al [26] and Lian Lu et al [28] are the only studies using this kind of algorithms for prediction in MGs.
- ✓ Simple prediction model based on indoor measurements proposed in [4].
- ✓ Holt-Winters forecasting method: also known as the Triple Exponential Smoothing [47] It is a statistical approach which consists of smoothing time series data using the exponential window function. [10] uses this algorithm for prediction in MGs.
- ✓ Intelligent Dynamic Grid Forecasting algorithm proposed by Harini Sekar et al in [13].
- ✓ Bayesian technique and Monte Carlo No-U-Turn Sampler method proposed in [14] and naïve bayes classification is used in [6].
- ✓ Online distributed/ centralized algorithm used in [24] and [25] respectively.
- ✓ Interacting Multiple Model Kalman Filter: based on probability, it is one of the most used algorithms for data fusion [48]. Among analyzed studies, only two use this algorithm which are [30] and [31].

4.3. Techniques for models training:

RQ3: Which techniques are used for training prediction models in MGs?

Techniques refer to how the prediction model is developed; if the solution is simple or hybrid, based on parallel computing, uses feature

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selection method and also if it is based on online or offline machine learning.

4.3.1. Optimization technique:

Some prediction solutions in MGs use optimization in their prediction process for different purposes. Table 9 lists the objective, the methods used to solve optimization problems and the references of concerned papers.

Table 8 : Optimization methods

Objective	Optimization method	References
Enhance the prediction	Extrapolation	[5]
Minimize the prediction error	NA	[8]
Select the parameters of the holt winter prediction equations	NA	[10]
Optimize the result of auto-encoders (SAE)	Genetic algorithm	[12]
Optimize predicted power and all relevant parameters	The python function MILP of the OPENOPT framework with solver glpk	[14]
Optimize SVR parameters	Lagrange multiplier techniques	[16]
Minimize the Root Mean Square Error	Structural optimization	[17]
Optimize the topology of the MLP	Script varying all possible parameters	[21]
Select the optimal set of actions under possible scenarios	Q-learning based optimization framework	[22]
Obtain optimal solutions that are robust against variations in the parameter values with respect to a nominal value (optimal worst-case scenario	Optimization approach that combines the worst-case analysis with a min–max formulation	[29]
Schedule operation according to the latest forecast information	Rolling optimization model	[31]
Economic dispatch considering generation, storage, and responsive load offers	Multiperiod artificial bee colony optimization algorithm	[32]
Optimize the network parameters	Quantum Particle Swarm Optimization (QPSO)	[34]

4.3.2. Simple/Hybrid technique:

Some studies propose simple prediction models and others are based on hybrid models.

✓ **Simple models**

In this case the prediction model is based on one algorithm. Table 7 lists the analyzed works based on simple prediction models and shows the techniques in each cases.

Table 9: Studies Based On Simple Models

Prediction model	References
Simple ANN	[5], [7], [15] [18] and [20]
simple prediction model based on indoor measurements	[4]
Simple fuzzy logic systems	[8], [29] and [17]
Regression trees	[9]
simple Holt-Winters forecasting method	[10]
Online centralized algorithm	[25]
Online distributed algorithm	[24]
simple chase	[26] and [28]
Q learning	[27]
simple markov chain and a simple naïve bayes classification	[6]

✓ **Hybrid models**

In this class the prediction model is composed of two or more algorithms, or of algorithms combined with optimization functions. Researchers propose this kind of prediction models with the aim of improving prediction performances by enhancing accuracy, decreasing training time and so on. Almost half of the analysed papers uses hybrid models for their prediction solutions.

Evolutionary algorithm is combined with ANN in [3] to search the better weight values of ANN to find a better solution in the solutions space when the training of ANN is terminated based on the early stopping condition. Clearness index is modeled in [14] based on parameters, each of which is associated to a coefficient which is the prior random parameter of Bayesian

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Inference and are evaluated assuming a Gaussian trend and applying the MC-NUTS Monte Carlo method simulation to calculate the relative values.

Three algorithms are incorporated in [21] to construct the prediction solution; first, the Self Organization Map (SOM) is trained for pattern recognition, then its output is used as an input for k-means algorithm to group automatically several neurons together under clusters (superclasses). Each cluster is trained thereafter based on MLP algorithm.

The hybrid prediction model proposed in [16] combines SVR with Grey Theory model. Mainly, the model goes through four steps. The first one consists of determining two weights of the hybrid model w1 and w2, and the second step constitutes the first iteration of the model where Grey Theory is the main prediction model. The second iteration of the model is executed in third step where the prediction model is based on the sum of Grey prediction multiplied by one of the two determined weights and SVR prediction multiplied by the other weights ((w1*SVR model)+(w2*Grey Theory model)). Finally, the fourth step describes later iterations where the previous errors of SVR and Grey Theory predictions are evaluated, then if SVR error is less than Grey Theory error, the prediction is the same as in the third step. Otherwise, the prediction model switches the weights of the model presented in the third step to give more impact to the more accurate prediction ((w2*SVR model)+(w1*Grey Theory model)).

Table 8 shows all the hybrid models studied in this SLR including those detailed previously.

Table 10: Studies Based On Hybrid Models

Prediction model	References
ANN with evolutionary algorithm	[3]
SVM incorporated with Sliding Mode Control	[11]
auto-encoders (SAE) and back-propagation (BP) algorithm	[12]
Bayesian technique and Monte Carlo No-U-Turn Sampler method	[14]
Hybrid of SVR and Grey Theory models	[16]
Empirical Mode Decomposition and SVR	[19]
ANN for pattern recognition, K-means for data clustering and perceptron for forecasting for each cluster	[21]
Reinforcement learning is used incorporated with Markov chain	[22].
Self -Recurrent Wavelet Neural Network and Levenberg-Marquard	[23]
Time series combined with kalman filter algorithm	[31]
ANN, Markov Chain and Linear Regression	[32]
Markov Chain and Bayesian networks	[33]
Adaptive Neuro-fuzzy inference system (ANFIS) prediction algorithm using Quantum Particle swarm optimization	[34]
Generalized Regression NN, Radial Basis function NN	[35]
Reinforcement learning using fuzzy reward	[49]

4.3.3. Offline/Online machine learning technique

Prediction solutions can be classified either as online or offline learning. Those techniques differ each one from the other on the way of training the prediction model. The most studies analyzed during this SLR are based on offline learning.

✓ **Offline models**

In this case the prediction model is trained only once because it is used in problems where data have the same characteristics. 23 analyzed studies in this SLR use offline learning technique for training the prediction model. Table 10 lists the references of all these studies and used algorithms in each model.

Table 11: Studies Based On Offline Learning

Algorithm	References
ANN	[3], [5], [7],[12], [15], [23], [32]
simple prediction model based on indoor measurements	[4]
Naïve bayes	[6], [14], [33]
Fuzzy logic systems	[8], [29], [34]
Regression trees	[9]
Holt-Winters forecasting method	[10]
SVM	[11], [16], [19]
Intelligent Dynamic Grid Forecasting algorithm	[13]
Markov chain + reinforcement learning	[22]
Q learning	[27], [49]
Kalman Filter	[30]

✓ **Online models**

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In this case, the prediction model changes continuously in order to be adapted of the changing characteristics of the data. Among analyzed works, ten studies are based on online learning which are presented in table 9.

Table 22: Studies Based On Online Learning

Algorithm	References
Real time Markov chain	[6]
stable Takagi & Sugeno fuzzy model	[17]
Backpropagation neural networks	[18]
ANN	[20], [21]
online centralized algorithm	[25]
online distributed algorithm	[24]
Chase	[26] , [28]
Time series with Kalman filter	[31]
Generalize regression neural network with basis function neural network.	[35]

4.3.4. Parallel computing technique

In this kind of techniques, the training dataset is divided into subsets and each subset is trained independently. Then, the trained models are merged to obtain the prediction results.

There are only 2 prediction studies in this SLR that are based on parallel computing. The first one is [21], where the proposed model consists of clustering the training set then, Perceptron algorithm is used for prediction in each cluster. In [35] the prediction process consists also of two stages, the first one is splitting the training set into subsets and training in parallel each subset using ANN, the second stage consist of the fusion of the results of trained models using dynamic weighted average method.

4.3.5. Feature selection technique

Feature selection is a technique which is widely used in machine learning prediction process. It mainly aims at reducing optimally the number of inputs of the prediction model without losing knowledge in order to enhance the prediction reliability and accuracy, to avoid overfitting and to reduce training time.

Among analyzed studies only four use feature selection techniques to identify relevant attributes for the prediction model. Irrelevancy filter and redundancy filter feature selection method is used in [3] and [23]. In [17] and [20] relevant output are selected based on correlation analysis. In [11], it is announced that feature selection is applied but no information about the used method is given.

4.4. Architecture:

RQ4: What is the architecture type in which prediction solutions in MGs are implemented: centralized, distributed or hybrid?

Concerning used architectures to implement prediction solutions, all analyzed studies are centralizes since they are implemented in a single point because they all deal with prediction at one MG.

4.5. Big data technologies:

RQ5: Is the prediction based on big data technologies?

Until today, there is just few numbers of existing prediction solutions in MGs which are based on big data analytics.

Among analyzed studies, only Zhenyu Zhou et al. use big data for power forecasting algorithm in [12] and [50]. In those papers data are processed based on deep neural networks as detailed in the subsection 4.2.1 of this SLR. Unfortunately no detail on big data techniques and implementation are given in those papers.

4.6. Prediction models performance evaluation

RQ6: For the solutions evaluation, which technique, simulation tool, and type of dataset are used?

✓ **Solution evaluation**

To evaluate the accuracy of prediction solutions in MGs, many methods of error computing are used. The majority of analyzed studies use known methods such as MAE, MSE… Some of them propose new formula to compute the error. Table 12 lists the references of papers using known prediction error computing methods.

Table 33: Error Computing Methods

Error computing method	References
MSE	[7], [15], [20]
RMSE	[8], [15], [17], [29], [33], [34]
MAE	[20], [29], [8]
MBE	[6], [15]
MAPE	[12],[16], [17], [18], [21], [32], [34], [35]
MANPE	[20],
NRMSE	[23]
NMAE	[23]

✓ **Data source for solution validation**

Validation of prediction models analyzed in this SLR is based either on simulation or on use

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case study. However the majority of them are based on simulation except [19] and [14] which has utilized use case study to validate the prediction model. Table 13 presents some details about data sources used in model validation of all analyzed papers.

Tableau 44: Data Sources Details

Validation Data sources details	Paper reference
Load data of the University of Calgary	[3]
PVA, built on the roof of the university, consists of 16 PV panels Solar-Fabrik SF-130/2-125 connected in series	[4]
RSE company microgrid. The microgrid mainly includes a photovoltaic field with 30 kWp, two storage systems a miniwind turbine and a controllable load.	[7]
Data from the microgrid installed in Huatacondo, which is located in northern Chile.	[8]
Data from a China location in 2007	[9]
HOMER for a village, Deogarh in the state of Madya Pradesh, India	[13]
25-kWp PV system Solar radiation data and meteorological measurement are obtained from experimental data collected by ENEA.	[14]
University of Zagreb Faculty of Electrical Engineering and Computing	[15]
First outdoor microgrid test bed, established by INER in Taiwan. The system consists of 21 units of l.5 kW HCPV, one unit of 65 kW microturbine, and 60 kWh lithium iron phosphate battery.	[16]
Company Doña Inés de Collahuasi and the Millennium Institute Complex Engineering Systems ICM: P-05-004-F, CONICYT: FBO16, CONICYT/FONDAP/15110019 and FONDECYT project 1110047.	[17]
Bed, established by Institute of Nuclear Energy Research (INER) in Taiwan	[18]
Grant and test bed hosted by Telekom Slovenija; by the FP7 project SUNSEED (FP7-ICT-619437); and the Slovenian Ministry of Economic Development and Technology.	[20]
Data from a microgridsized environment provided by the Spanish company Iberdrola	[21]
The building in BCIT from May 2012 to February 2013	[23]
From the traces of power consumption in the Southern California Edison (SCE) area recorded in 2011	[25]
College in San Francisco with yearly electricity demand of around 154GWh.	[26]
Data acquired from a 25kW PV park located in Attica Greece with sample time of 300sec	[27]
Microgrid in Huatacondo, Chile	[29]
Offline EMS simulator, with real consumption, solar, and wind power data	[33]
Real Microgrid dataset in Hong Kong	[35]
No information	[31], [32], [34], [22], [19], [12], [6], [10], [11], [30], [5], [28]

- ✓ **Simulation tool**

Among analyzed studies only 7 specify adopted simulation tool. These are MATLAB, R and Python. The following table presents the references of studies using each tool.

Table 55: Simulation Tools

Tool	Reference
MATLAB	[31], [4], [6], [20]
R	[10]
Python	[14]

4.7. Results and discussions:

The elaboration of this SLR allowed us to obtain some results about the state of the art of existing prediction models in MGs, make findings on these models and extract some points which are listed in this section.

Prediction models used in MGs:

The majority of prediction solutions in MG are based on machine learning algorithms: ANN is the most commonly used machine learning algorithm, especially for short term load forecasting, followed by SVM (8 %) and Reinforcement learning (8 %).

There are some studies which are based on probabilistic algorithms such as Markov chains (8 %) and Fuzzy logic systems (13, 5 %).

Some studies use hybrid prediction models and others use simple ones. Furthermore, the number of analyzed works based on offline learning is more important than those based on online learning.

Only two papers consider parallel prediction models. This technique is very useful in case of prediction studies based on big data analytics, because it divides the original database into subsets which are easy to handle and record better result at accuracy and training time levels.

Little number of studies considers feature selection technique in the prediction model. But, with the development of MGs, many valuable attributes will be collected from the electricity network, if they are all taken as inputs for the prediction model, this could have a negative impact on accuracy and training time of the model. Hence the importance of this technique which allows extracting the best attributes to ensure best accuracy.

Concerning optimization techniques, various methods are used in prediction models in MGs, and it is mainly to optimize prediction algorithm parameters or to minimize the prediction error.

It should be noted that each algorithm or technique is suitable with specific prediction solution, for example online learning technique is appropriate in case new data are generated constantly by sensors, mobile applications or other intelligent devices making the model obsolete and there is a need of quick predictions as in the case of electricity outage prediction.

✓ **Big data technology**

Till today the number of prediction solutions in MGs that use big data technology to leverage their solutions remains low. Consequently, researchers must give more interest to prediction studies based on big data analytics because MGs are evolving and becoming smartest by the introduction of more and more IoT technologies. This will result in rapid growth of the amount of data generated in MGs where the processing unit should exploit big data tools to construct prediction models with high performances.

✓ **Prediction solution implementation architecture**

There are many types of implementation architectures of prediction solutions. We can find distributed architecture, where the communication is possible between all nodes of the network, centralized architecture where the communication is federated by one node and also hybrid architecture which combines between the two types. There are also special architectures which are based on peer to peer technology such as [40] and [41].

All analyzed papers in this SLR propose prediction solution for one MG and there is no existing study that considers the implementation of forecasting solution in an electricity network composed of interconnected MGs. Nevertheless, there are some studies which propose the implementation of control systems in distributed architecture such as [38] and [39]. We have not considered those studies in our SLR because they don't propose prediction models and some of them exploit just the result of some prediction solutions which have been already conducted.

5. CONCLUSION

There is a growing number of studies which address prediction in MGs. But till today, there is no existing SLR that analyzes those works. This paper constitutes the first developed SLR which identifies, quantifies and evaluates developed prediction models in MG regarding multiple dimensions which are: prediction distribution, prediction goal, used algorithms, model setting techniques (parallel/serial techniques, online/offline, optimization …), implementation architectures and performance evaluation. We have also identified that there is no proposed study that considers big data analytics to construct the prediction model.

The presented SLR institutes a clear understanding of the state of the art of existing prediction models and detects their main limitations. We are working on a prediction solution based on big data technologies and peer to peer architecture.

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