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# A self-adaptive evolutionary fuzzy model for load forecasting problems on smart grid environment

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## HIGHLIGHTS

- Novel hybrid self-adaptive forecasting model optimized using meta-heuristics.
- Real-time parameter optimization during the learning process.
- GRASP solution generator guided by values from feature extraction techniques.
- An expert mechanism for refining model's inputs using a neighborhood structures.
- Results point out efficient MG load forecasting with low variability over MAPE.

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## ABSTRACT

The importance of load forecasting has been increasing lately and improving the use of energy resources remains a great challenge. The amount of data collected from Microgrid (MG) systems is growing while systems are becoming more sensitive, depending on small changes in the daily routine. The need for flexible and adaptive models has been increased for dealing with these problems. In this paper, a novel hybrid evolutionary fuzzy model with parameter optimization is proposed. Since finding optimal values for the fuzzy rules and weights is a highly combinatorial task, the parameter optimization of the model is tackled by a bio-inspired optimizer, so-called GES, which stems from a combination between two heuristic approaches, namely the Evolution Strategies and the GRASP procedure. Real data from electric utilities extracted from the literature are used to validate the proposed methodology. Computational results show that the proposed framework is suitable for short-term forecasting over microgrids and large-grids, being able to accurately predict data in short computational time. Compared to other hybrid model from the literature, our hybrid metaheuristic model obtained better forecasts for load forecasting in a MG scenario, reporting solutions with low variability of its forecasting errors.



## 1. Introduction

Electric grids are evolving from a centralized single supply model towards a decentralized bidirectional grid of suppliers and consumers. In this new environment, so-called Smart Grid (SG), the reality becomes a more dynamic scenario involving uncertainty in energy production, consumption and distribution. The development of efficient algorithmic techniques that deal with these scenarios is crucial for supporting this important economical activity.

Rogers et al. [1] highlighted that the demand side, the consumers, will have to adapt to the available resources, in contrast to the current model in which the supply should always match the demand. In most countries, the starting point in the migration to this new business model and the implementation of the SG is the installation of smart meters [2] and sensors in residences and commercial buildings. The need for reducing environmental

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impacts, as emissions of greenhouse gases, lead to an increasing use of renewable energy systems (primarily wind and photovoltaic units) [3].

Considering measurement systems with high sampling rates over years of data acquisition [4], one can expect a large amount of detailed data. In case of electrical network metering, this data can be converted into valuable and useful information, which is crucial for the success of a wide range of SG applications. A task that has been left to the researchers is the one related to the selection and analysis of parts of these datasets. From such data treatment, those huge datasets become available in different ways in order to allow researchers from distinct areas to develop smart solutions for multifunctional and highly complex problems.

Lee and Tong [5] underscore the importance of energy consumption forecasting in the context of economic development of a country due to the large and rapid changes in the industry, which have strongly affected energy consumption. Taylor and McSharry [6] emphasized that electricity demand forecasting is of great importance for the management of power systems. Nowadays, it is a consensuses that electrical load forecasting assisted by Artificial Intelligence method plays a vital role for an effective success of the SG [7].

The need for Short-Term Load Forecasting (STLF) for controlling and scheduling of power systems is increasing, a task that is also required by transmission companies when a self-dispatching market is in operation. Commonly, in STLF studies one is interested in predictions for the next 1–24 h ahead samples in basis of half-an hour or one-hour [8]. Nowadays it is also possible to find research reporting shorter time periods, such as Guangui et al. [9], who studied wind power energy forecasting with 15 min of forecasting horizon. Furthermore, real-time forecasts will not be useful only for wind or solar forecasts, as it is already a need when considering Microgrids control and efficient management [10].

In terms of STLF, MG should be taken into account, since they are more difficult to be monitored and predicted than large power grids due to their higher randomness and lower autocorrelation factors [11]. MG had become a basic and fundamental infrastructure in the SG environment and have been receiving attention in recent literature work. For instance, Zhi-Chao et al. [12] used a backpropagation neural network to perform forecasts over a MG environment, however, the accuracy of their results had been compromised due to large load variations in the small office building that they had analyzed. A problem that generally does not happen in Large-Grid and Medium-Grid environments, as can be verified in Taylor and McSharry [6], where STLF was performed over a huge European data set from 10 different countries. As emphasized by Coelho et al. [13], forecasts and, in special, probabilistic forecasts will assist decision making in MG, guiding and assisting suitable and profitable energy storage. Forecasts of load and prices are also being considered for auction-based market, where the length of a market period has been modeled as an interval between 15 min and one hour, which is included in the category of STLF [14]. Hernández et al. [15] focus on Artificial Neural Networks (ANN) approach for STLF in order to provide useful information for MG intelligent elements, in case they can adapt their behavior depending on the future generation and consumption conditions.

Recent works have proposed artificial intelligence techniques for dealing with load forecasting problems in applications where traditional forecasting methods have many limitations to tackle big data and higher load fluctuation [16], such as ANN [17], fuzzy inference systems (FIS) [18,19] and Fuzzy Times Series (FTS) [20,21], support vector machines (SVM) [22] and hybrid heuristic models [23,24].

Most forecasting models require feature extraction techniques in order to select good quality inputs [25]. Different works in the literature had already tried feature extraction for improving forecasting performance, specially for ANN [26]. Enayatifar et al. [21] obtained the Fuzzy Logical Relationships (FLRs) by analyzing the Autocorrelation Function (ACF). Recently, Lahouar and Slama [27] proposed the use of ACF to assist a mechanism for input selection of a random forecasting model. However, feature extraction from the time series is not the only viable solution to selecting possible sets of model's inputs, this problem has been also approached with the use of bagging [28].

Driven by theoretical and real world applications, extracted from the literature and envisioned by the authors of this work, the purpose of our current paper is to use a class of bio-inspired metaheuristics for calibrating the parameters of a model based on *if–then* fuzzy rules. We incorporated the power of the evolutionary algorithms for optimizing the fuzzy rules and calibrating their parameters, while Neighborhood Strucutures – NS are used for searching for a prominent set of lags. The expert input selection done by the NS, along with the evolution process, modify and adjust the model inputs during the training phase. In this context, *Evolution Strategies* – ES [29] stand out as a robust and flexible framework, which has been effectively applied for solving many combinatorial optimization problems [30,31], however, up to the moment, with only sparse/none results reported over forecasting problems. A hybrid heuristic algorithm based on Greedy Randomized Adaptive Search Procedures – GRASP [32] and ES is proposed. The GRASP is used to generate the initial population of the ES procedure. Each solution, initialized as a different forecasting model, is generated according to a randomized solution generator in connection with a feature extraction technique.

The need to develop high accurate models for energy consumption forecasting is imminent, starting from simple data mining and noise suppression methods to more complete and efficient machine learning algorithms. Grosman and Lewin [33] use an algorithm based on the concept of Genetic Programming – GP [34] to generate a prediction model for dynamic control with nonlinear assumptions. Kashid and Maity [35] proposes a model based on GP for summer monsoon rains forecasting across India territory. Vladislavleva et al. [36] perform a forecasting model for predicting power output of wind farms based on meteorological data, using a hybrid method, integrating symbolic regression with GP. Recently, Çelekli et al. [37] propose a hybrid model, combining ANN with Gene Expression Programming (GEP) [38], to a manufacturing metallurgy problem, involving the forecasting of sorption of an azo-metal.

However, MG can reveal additional problems and requirements for forecasting systems [11]: (1) compared to large power grid, the load of micro-grid is more difficult to forecast given the smaller capacity and higher randomness; (2) complex forecasting models would increase the requirement and cost on computational resources, leading to difficulty in application and promotion among users; (3) the relationship between load characteristics and the corresponding forecasting accuracy lacks analysis and summary.

In addition, for ensuring forecasting accuracy of the proposed framework in real time systems, the use of metaheuristics based models offers flexibility for using the methodology on normal computers or embedded terminal devices. In view of the short demand of computational resources during the learning process, a real time update strategy is proposed, which represents an important advance for microgrid forecasts.

Dealing with load forecasting in different real databases, involving short-term forecasts on large grids and MG poses a great challenge. Thus, this paper tackles this issue by proposing a flexible open-source framework. The major contributions of this current work are:

- Propose a hybrid self-adaptive forecasting model with real-time parameter optimization during the learning process.