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Electricity demand and spot price forecasting using evolutionary computation combined with chaotic nonlinear dynamic model

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ABSTRACT

This paper proposes a new hybrid approach based on nonlinear chaotic dynamics and evolutionary strategy to forecast electricity loads and prices. The main idea is to develop a new training or identification stage in a nonlinear chaotic dynamic based predictor. In the training stage five optimal parameters for a chaotic based predictor are searched through an optimization model based on evolutionary strategy. The objective function of the optimization model is the mismatch minimization between the multi-step-ahead forecasting of predictor and observed data such as it is done in identification problems. The first contribution of this paper is that the proposed approach is capable of capturing the complex dynamic of demand and price time series considered resulting in a more accuracy forecasting. The second contribution is that the proposed approach run on-line manner, i.e. the optimal set of parameters and prediction is executed automatically which can be used to prediction in real-time, it is an advantage in comparison with other models, where the choice of their input parameters are carried out off-line, following qualitative/experience-based recipes. A case study of load and price forecasting is presented using data from New England, Alberta, and Spain. A comparison with other methods such as autoregressive integrated moving average (ARIMA) and artificial neural network (ANN) is shown. The results show that the proposed approach provides a more accurate and effective forecasting than ARIMA and ANN methods.

1. Introduction

Accurate forecasting of the electricity demand and spot price is essential in the operation of electric power system, especially in deregulated electricity markets. Along with the forecasted electricity prices, producers can develop bidding strategies to maximize profits and minimize risks, while consumers can allocate purchases between long-term bilateral contracts and spot markets. Accurately forecasting electricity price and load demand are necessary for investors to optimize portfolios [1]. Transmission congestion, maintenance schedule of generation units, fuel or water supply, etc., might affect the electricity price dramatically, complicating the forecasting problem [1–3].

A number of papers dealing with short-term load forecasting have been reported in [1,4–15]. Ref. [4] provides a comprehensive review of many methodological issues and techniques which have become innovative in addressing the problem of forecasting daily loads. The range of approaches for generating forecasts includes exponential smoothing [5] and neural networks [1,6]. Interesting approaches based on chaos theory were proposed in [7–16]. More recently hybrid approaches have been proposed in [17,18].

A considerable number of techniques of forecasting day-ahead prices are described in the literature. Techniques based on ARIMA models were presented in [2,19,20]. Ref. [21] provides a comprehensive review of some main methodological issues and techniques which have become innovative in addressing the problem of forecasting daily loads and prices in the new competitive power markets. In [1,22–24] neural network approaches were proposed to forecast short-term electricity price. A GARCH forecasting model to predict day-ahead electricity prices was proposed in [25]. An approach based on fuzzy classification was shown in [26], whereas wavelet transform models were discussed in [27] and an interesting hybrid approach is presented in [28]. Finally, models based on chaos theory were presented in [29–33].

Some believe that electricity demand seems random, but some believe that it seems chaotic, due to the influence of many complicated facts such as temperature, price of electricity and many other factors [7–16]. Similarly the price of electricity depends on the supply and demand of the market and the operating conditions of the transmission network, which are influenced by many factors, such as the climate, the economic situation, the planning for development, accidents and failure [29–33]. The joint effect of these factors results in complicated dynamics of electricity demand and

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Nomenclature

Indexes	
N	length of historical time series
M	number of desired steps-ahead prediction
nTr	dimension of the training set vector
Parameters	
μ	number of parents used in evolutionary strategy (ES)
γ	number of offspring used in ES
S	vector of the time series data values
$\hat{y}_{z,i}$	real value of time series
σ	standard deviation vector
TSD	historical time series data (an $N \times 1$ vector dimension)
SSR	the state space reconstruction set
TRN	the training set
Variables	
$\mathbf{x}$	vector of variables correspondent to input parameters of PREDICT2
x_j	input parameter j of PREDICT2
$\mathbf{x}_{\max}$, $\mathbf{x}_{\min}$	maximum and minimum limits of vector of variables correspondent to input parameters of PREDICT2
m	dimensionality of embedding space
τ	time delay
k	size of the local neighborhood
λ	the Euclidian distance metric
RF	type of regression functions of local constant models or method of computing the prediction output
$y_{z,i}$	prediction value of time series
Output^i	the $(nTr \times 1)$ column vector whose elements $\hat{y}_{z,i}$ are the nTr-step-ahead prediction results, using PREDICT2 associated to ith individual candidate

price. Usually statistics methods are employed to develop forecasting models for electricity price and load.

Recent developments in nonlinear dynamics have demonstrated that irregular or random behavior in natural systems may arise from purely deterministic dynamics with unstable trajectories. Even though some observations might appear random, there may exist an order or pattern beneath such an appearance. Such types of nonlinear dynamical systems, which are also highly sensitive to initial conditions, are known as chaotic systems [34,35]. Furthermore, if the seemingly random evolution of the electricity demand or price also possesses a chaotic trait, the theory of probability and statistics is not accurate enough to study both as a stochastic variable [7–16,29–35]. Instead, the chaos theory can be used to reveal its intrinsic regularity until more accurate and rational analysis results and prediction models are obtained [7–16,29–35].

The quality of a forecaster based on chaotic dynamics is highly dependent on parameters of the time series dynamics. Generally the parameters are assessed at the system characterization stage. Regarding forecasting precision, most of the chaos based methods have good performance for short-term chaotic time series forecasting. On the other hand, for stochastic time series and time chaotic series under high embedding dimension, the chaos based methods do not present a good behavior. Thus, a judicious time series analysis and/or hybridization with other methods are necessary to improve the time series forecasting to any kind of time series.

This paper presents a novel hybrid nonlinear chaotic dynamic and evolutionary strategy-based approach for multi-step-ahead time series forecasting. The fundamental and novel contribution of the paper is the insertion of a new training or identification stage into a nonlinear chaotic dynamic based predictor. In this training stage, five optimal parameters for a nonlinear chaotic dynamic based predictor are searched through an optimization model based on evolutionary strategy. Hence a common identification objective is used to minimize the mismatch between model prediction and observed data. For this purpose, an optimal time series identification stage is developed to find a model with good prediction capabilities. Thus, this paper proposes a new robust hybrid model for multi-step ahead prediction of time series regardless if the time series follows a chaotic, stochastic, and/or any other type of dynamic behavior.

The proposed approach is applied for multi-step ahead prediction of load and price and it is also compared with traditional techniques like ARIMA and ANN models. The load and electricity price data of New England, Alberta, and mainland Spain are used to corroborate the ideas and to obtain the results.

The paper is organized as follows: Section 2 provide the details of the proposed hybrid nonlinear chaotic dynamics and evolutionary strategy based approach, Section 3 presents numerical results of the simulations and Section 4 discusses the conclusion.

2. An hybrid approach based on nonlinear chaotic dynamic and evolutionary strategy

2.1. Times series prediction by chaotic nonlinear dynamics

The theoretical fundaments of times series forecasting using chaotic nonlinear dynamic methodologies is out of scope of this paper. The interested reader is referred to [34,35] for a better discussion.

A landmark in the chaos signal processing was made with the origin of embedding theorem of Takens [34,35]. This theorem explored the time-lagged vectors to realize the underlying dynamics, whereby, a dynamic of a real process result in a time series $\eta(t) = \{\eta(t_0 + n\tau)\}$ is sampled at intervals τ and initiated at t_0. Consider a dynamical system with a m-dimensional space and an evolving solution $g(t)$. For some observation, the lag vector can be defined as:

$$\eta(t) \equiv \left\{\eta_t, \eta_{t-\tau_1}, \eta_{t-\tau_2}, \eta_{t-\tau_3}, \ldots, \eta_{t-\tau_{m-1}}\right\}. \tag{1}$$

Then, under general conditions, the space of vectors $\eta(t)$ generated by the dynamics contains all of the information of the space of solution vectors $g(t)$. The mapping between them is smooth and invertible. This property is referred to as the embedding theorem. Thus, the study of the time series $\eta(t)$ is also the study of the solutions of the underlying dynamical system $g(t)$ through a particular coordinate system given by the observable η.

The embedding theorem establishes that, given a scalar time series from a dynamical system, it is possible to reconstruct a phase space from this single variable, that is, in theory, an embedded space with dimensions consisting of various time lags of the variable itself. The embedded space can also be created from many dynamic variables. According to the embedding theorem, the underlying structure cannot be seen in the space of the original scalar time series, rather only when unfolded into an embedded (or phase) space. Time series can correspondingly be forecasted based on this structure in the phase space. The purpose of the