Hourly solar energy forecasting using ARMA models ☆

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Abstract

We develop hourly auto-regressive moving average (ARMA) models to forecast solar energy. We use statistical tests to validate the model and construct hourly samples. These samples can be used as scenarios for energy planning or in stochastic optimization models.

Keywords: ARMA, solar energy, forecasting

1. Introduction

Increasing penetration of renewable energy sources, such as wind and solar, in the electricity grid requires good day-ahead power forecasts. Solar power differs from wind power due to its diurnal nature and it can have much greater minute ramps than wind [1] . In this article, we focus on forecasting hourly solar power. Forecasting methods for solar power are broadly divided into two categories: (i) physics-based models—these models predict solar power from weather and solar irradiation data, and (ii) statistical models—these models forecast solar power directly from historical data. Comparisons of these two methods are also available; see, e.g., [2, 3]. There are other approaches available as well which combine these two methods [4]. We study the statistical method alone, and specifically use auto-regressive moving average (ARMA) models to develop our forecasts. ARMA models are widely used for forecasting many economic and planning processes; see, e.g., [5]. They have also been used to forecast wind wind power [6, 7], as well as solar power [8, 9]. Here, we describe an in-depth summary of the methodology to forecast solar power using ARMA models.

2. Methods

We take hourly year-long historical solar power output from [10]. We use approximately nine months of data for training. The data does not have any solar power for the ten hours [20:00-5:00], and hence we restrict the forecasts in these hours to be zero as well. For each of the remaining 14 hours of the day, we build an ARMA(p, q) model. Further, for each hour, we verify the stationarity of the time series. For each hour, we test a number of ARMA(p, q) models and find the best one. We use statistical tests on the residuals to validate the model. Finally, we use Monte Carlo sampling from the best ARMA model, for each hour, to create hourly scenarios. Below we provide more details.

2.1. Stationarity

First, we test the hourly data for stationarity using the Augmented Dickey-Fuller (ADF) test [11]. The ADF test has a null hypothesis that the series includes a unit root (or, is non-stationary). We reject the null hypothesis at a level 0.05 if the test-statistic exceeds its 0.95 level quantile. For all the 14 hours of the day, the null hypothesis is rejected suggesting the series may be stationary, and hence an ARMA model may be suitable.

2.2. Selecting parameters of the ARMA model

Next, we estimate the parameters of the ARMA model—p, the order of the autoregressive part and, q, the order of the moving average part. For each hour, we construct 16 models with both p and q between 1 and 4, and compute the loglikelihood objective function value. Next, for each hour, we calculate the Bayesian information criteria (BIC) for the 16 models using $p + q + 1$ parameters. The BIC penalizes for models with more parameters, and the smallest value of the BIC gives the best model, for each hour. Table 1 provides our estimated p and q values for the 14 hours of the day. We note for none of the hours an order of more than two is needed.

Table 1: Estimated p and q values for ARMA(p, q) models for 14 hours of the day.

Hour	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
p	1	1	1	1	2	1	1	1	1	1	1	1	1	2
q	1	1	1	1	1	1	2	1	1	1	1	1	2	1

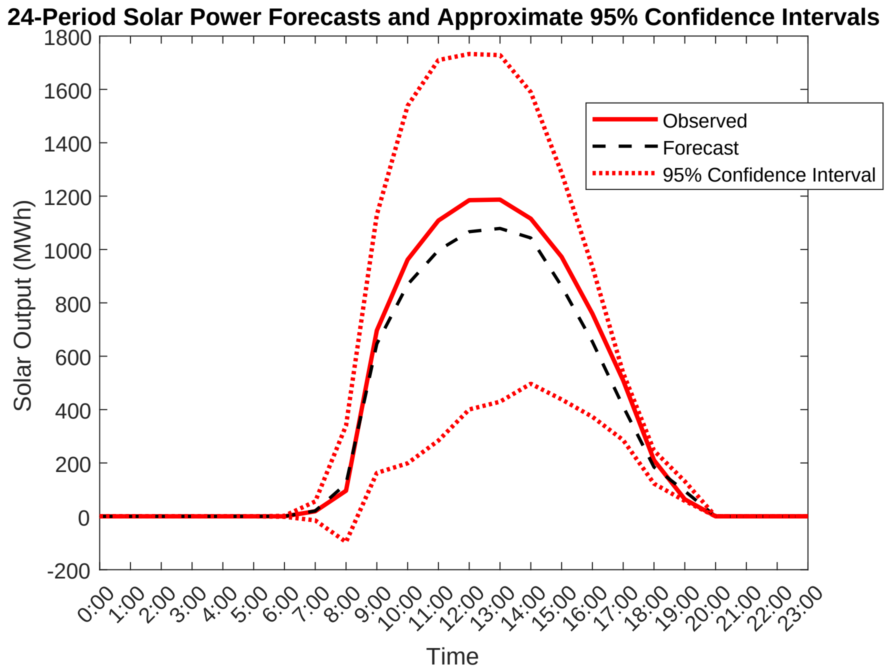

Figure 1: Day ahead actual and predicted values using ARMA models from Table 1

2.3. Prediction

Figure 1 plots a day-ahead prediction using the above constructed ARMA models; i.e., one hour ahead predictions from the 14 ARMA models. The mean absolute error between the actual and the predicted series is 39.6, or 3.3% of the maximum actual value. The root mean square error between the actual and the predicted series is 61.0, or 5.1% of the maximum actual value.

We further verify autocorrelation in the series, for each hour, using the Ljung-Box test [12] on the residuals for a lag of 5, 10, 15 hours. The Ljung-Box test has a null hypothesis that the residuals are uncorrelated up to a given lag. We reject the null hypothesis at a level 0.05 if its test-statistic exceeds its 0.95 level quantile. For all the 14 hours of the day, the null hypothesis is not rejected suggesting a zero autocorrelation in the series or appropriate models.

Finally, we use Monte Carlo sampling to generate 2000 hourly solar power scenarios. The output from an ARMA model is real valued, and hence can be negative. We truncate the negative powered outputs to 0. For the 14 hours of the day, the sampling resulted in 1.6% of the outputs with estimated power output below -5MWh. Figure 2 plots the 2000 day-ahead scenarios as well as the

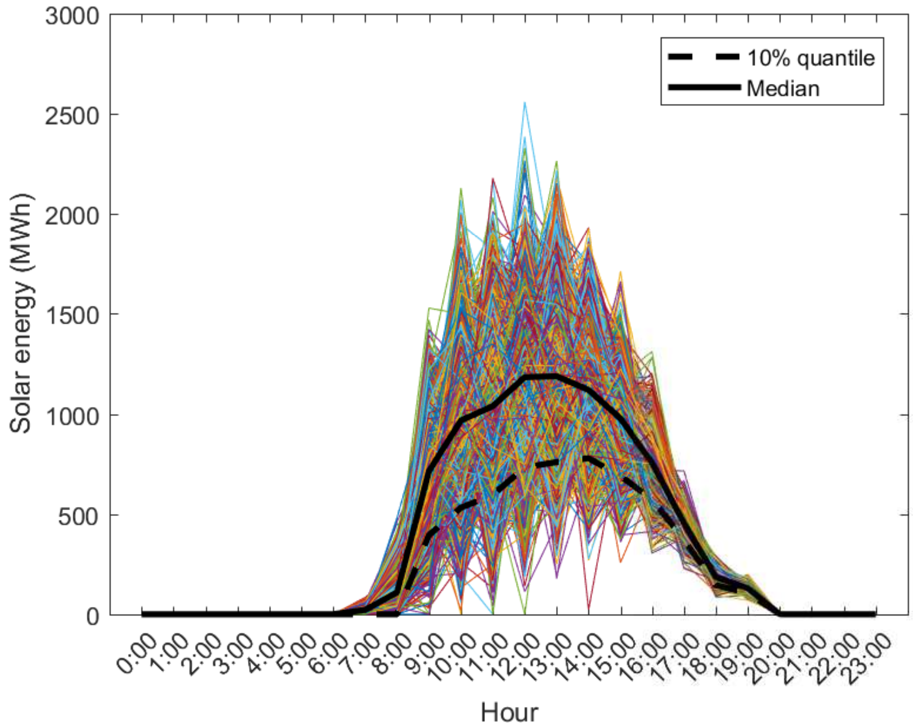

Figure 2: 2000 hourly scenarios for solar power generated using the ARMA models from Table 1. The dashed black line is the median hourly value, and the solid black line is the 10 percentile solar energy value.

median and 10 percentile values.

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