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# Solar Radiation Modeling with Adaptive Approach

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## Abstract

The unsustainable formation of fossil fuels, increase the interest on different resources and this leads to greater emphasis on clean resources. Solar energy is one of the popular sources among the renewables. Electricity generation from PV panels directly related to the solar radiation value measured on surface of the panel. Modeling of solar radiation is important due to manage the integration of different sources to the grid. In this study, previously developed Adaptive Approach method is used for modeling the solar radiation values. This method combines linear prediction filter method with an empiric approach. Linear prediction filter used in this study utilize the current value of the solar radiation to predict next hour's solar radiation value while the empiric model utilize from the current value of the solar radiation and the deviation on extraterrestrial radiation. One year solar radiation data belong to Van region is used in this study. The accuracies of the forecasting results are compared and discussed.

## Key words

Solar radiation forecasting, Adaptive approach, Empiric model, Linear prediction filter

## 1. INTRODUCTION

The best solutions for alternative energy sources, such as some of the solar energy and photovoltaic (PV) systems are rapidly gaining acceptance [1]. In order to integrate the electricity generated by solar energy into the grid, solar irradiation must be reasonably well forecasted, where deviations of the forecasted value from the actual measured value involve significant costs [2]. Several methods are used before for solar radiation forecasting. [3] used the combination of unsupervised k-means clustering algorithm and artificial neural networks (ANN) for hourly global horizontal solar radiation forecasting. They show that the combination of these models provide better results. In [2] a univariate Dynamic Harmonic Regression model set up in a State Space framework for short-term solar irradiation forecasting is proposed. This method is based on the frequency domain and provides a fast automatic identification and estimation procedure. Their results show that the Dynamic Harmonic Regression achieves the lowest relative Root Mean Squared Error for a forecast horizon of 24 h ahead. In [1] neural networks to predict solar radiation is used. They categorized the review under three major performance schemes such as delay, number of neurons and activation function for establishment of neural network architecture.

[4] applied Support Vector Regression (SVR), Gradient Boosted Regression (GBR), Random Forest Regression (RFR) as well as a hybrid method to combine them to downscale and improve 3-h accumulated radiation forecasts provided by Numerical Weather Prediction (NWP) systems for seven locations in Spain. They showed

that Machine Learning methods are quite effective. In [5] a novel solar radiation forecasting method based on a novel game theoretic self-organizing map (GTSOM) is proposed. They compared the proposed method with that of the K-means and the original SOM. They show that comparison demonstrates the superior performance of the proposed approach. [6] used satellite data to improve solar radiation forecasting with Bayesian Artificial Neural Networks. They show that forecasting skills are improved by including exogenous inputs to the model by using global horizontal solar irradiance satellite data from surrounding area.

In [7] linear prediction filter approach for hourly solar radiation forecasting is proposed. In this approach solar radiation time series is converted to 2-D image and this new form of the data provide better understanding about the seasonal and daily behavior of the solar data. The optimum filter coefficients are determined by scanning image with a filter template. [8] improved the linear prediction approach by developing multi-dimensional filter templates. In their method, the images obtained from different time series such as temperature, extraterrestrial and solar radiation data etc. are linked each other with filter templates. This method provides utilize from different parameters for solar radiation forecasting and up to 40% improvement is achieved as per to linear prediction filter approach. In [9] a novel adaptive approach (NAA) for solar radiation forecasting is proposed. This approach integrates an empiric model to linear prediction filter approach to improve the prediction accuracy. The solar radiation data are predicted using different methods for different weather condition cases. Two different strategies are used to decide the prediction method. Seasons and clearness index values are employed to select the forecasting method. The results show that the accuracy of the forecast is considerably improved using proposed adaptive prediction approach.

In this paper, the adaptive approach method which is developed previously [9], is employed to determine next hour solar radiation values. The clearness index values are used to determine the forecasting method. If the clearness index value is greater than a specified value, linear prediction filters otherwise an empirical model is used. The solar radiation data belong to Van region is used to test the performance of the adaptive approach method. The organization of the paper is as follows. The data used for this study are described in Section 2. The adaptive approach method is explained in Section 3. The experimental results are illustrated in Section 4. Finally, conclusions are explained in Section 5.

## 2. DATA USED

In this study, solar radiation data belong to Van region of Turkey is used. Van region has a good insolation characteristic as seen in Fig. 1. The solar radiation data belong to Van region is taken from the Turkish State Meteorological Service (DMI). The variation in the solar irradiance value over a 1-year period from 2014 is shown in Figure 2. The extraterrestrial irradiance is the intensity of the sun at the top of the Earth's atmosphere [8,10]. Therefore, the actual measured data on the earth's surface must be less than the extraterrestrial irradiance.

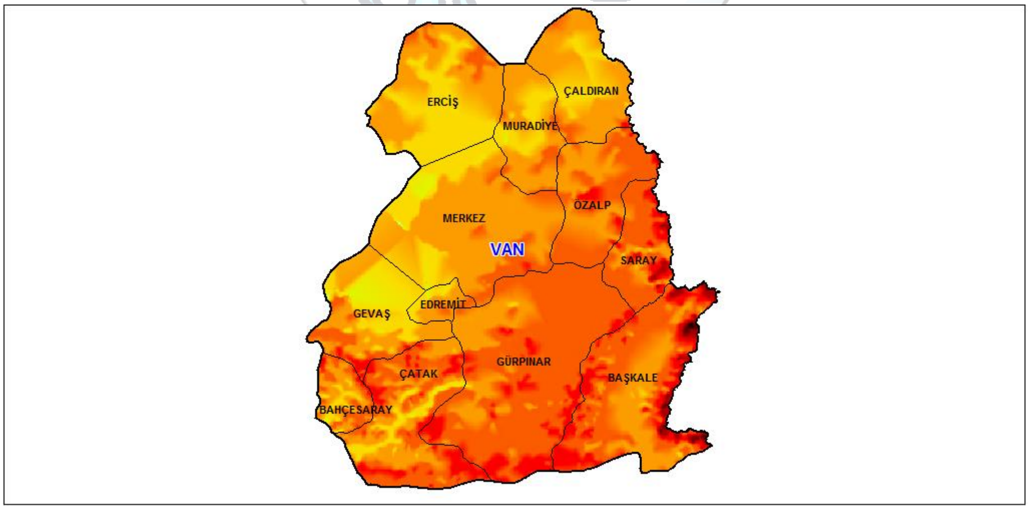


*Figure 1. The insolation map of the Van region*

The extraterrestrial irradiance can be calculated as follow:

$$I_s = CSin(\varphi)/24R^2 \qquad (1)$$

where $I_s$ is the total radiation falling on the atmosphere; $C$ is the solar constant assumed to be 1367 (W/m$^2$); and $R$ is the solar radius vector (assumed to be 1). Then the solar elevation angle is calculated by using following equation:

$$sin(\varphi) = sin(L)sin(D) + cos(L)\cos(D)\cos(h) \tag{2}$$

Here, $L$ is the latitude of the location, $D$ is the declination angle of the sun, and $h$ is the solar hour angle. Forecasting model is selected by using clearness index values. These values are calculated by dividing solar radiation value to extraterrestrial radiation value for each hour [11] as seen in Eq. 3:

$$K_t = I / I_0 \tag{3}$$

Here, $K_t$, $I$ and $I_0$ represent the clearness index, solar radiation and extraterrestrial radiation, respectively.

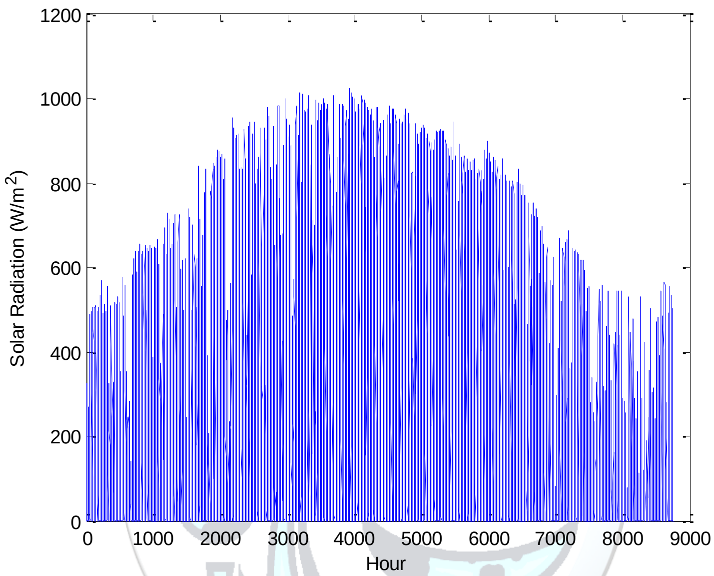


*Figure 2. Variation of the solar radiation data over a 1-year period*

## 3. ADAPTIVE APPROACH METHOD

The adaptive approach method includes combination of linear prediction filters and an empiric model. For a better understanding, linear prediction filter and empiric model used are explained in this section. Linear prediction filters for solar radiation forecasting are firstly introduced by [7]. In this approach solar radiation time series is converted to 2-D image. This image provides better understanding of seasonal and daily behavior of solar radiation. Furthermore, image processing techniques can be applied to this data after conversion. Linear prediction filter scan overall image and optimum filter coefficients which will be used for prediction are determined. In this study, filter template which use the actual data to predict one hour later data is used. Consider the 2-D linear prediction filter as follow:

| | |
|---|---|
| $Z_{i,j}$ | $Z_{i,j+1}$=? |

(4)

The prediction pixel was determined by using past pixels with the following formula:

$$\check{Z}_{i,j+1} = Z_{i,j}.a_1 \tag{5}$$

$i$,$j$ and $Z_{i,j}$ are identify the row and column number of the pixel and the pixel value, respectively. In 2-D linear filter approach, the estimation $\hat{Z}_{i+1,j+1}$ is considered as a linear combination of past samples. After calculated prediction error for each ($i$,$j$) coordinates, the energy of total prediction error is calculated with Eq. 6:

$$\varepsilon = \sum_{i=2}^{m} \sum_{j=2}^{n} \varepsilon_{i,j}{}^{2} \tag{6}$$

where *m* and *n* identify the size of image. By equating to zero the derivative of this function, the filter coefficients which minimize the Eq. 6 are obtained and the solution yields the following equation:

$$\begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix} = \begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} \tag{7}$$

where $R_{ij}$ is the correlation value between the past values, $a_i$ is the linear filter coefficients and $r_k$ is the correlation between the past and predicted pixel.

2-D linear prediction filters have a good forecasting performance but this approach good at linear data. The solar radiation data generally nonlinear due to weather conditions such as rain, wind, cloud etc. To overcome this weakness, an empiric model can be integrated to the linear prediction filters [9]. The empiric model used in the adaptive approach method is as follow:

$$S(t+1) = S(t) + (E(t+1) - E(t)) \tag{8}$$

In this empiric approach, the next hour solar radiation value is calculated by summing the solar radiation with the difference of actual and next hour extraterrestrial radiation. In the integration strategy, clearness index value is employed to decide which method will be used in prediction. Clearness index value is the ratio of solar radiation to the extraterrestrial radiation in a certain time and formulated with Eq. 3. In the used strategy, if the clearness index value is smaller than 0.5, the next hour solar radiation value is predicted by empiric model otherwise; the linear prediction filters are employed.

## 4. EXPERIMENTAL RESULTS

In this study adaptive approach method is used for hourly solar radiation forecasting. In this paper clearness index value is employed to decide combining strategy of adaptive approach method. The solar radiation data belong to Van region of Turkey is used to test this method. Van region has a good insolation characteristic. The Root Mean Square Error (RMSE) and Mean Bias Error (MBE) assessment criteria are used to evaluate the performance of adaptive approach method. The RMSE is a commonly used measure of the differences between the values extracted by a forecasting model and the observed values. The value of RMSE provides information on the short term performance [12]. The MBE provides information in the long term performance of the correlations by allowing a comparison of the actual deviation between predicted and measured values term by term. The MBE is used to describe whether a model over-(positive value) or under-(negative value) predicts the observation and has the same units as the measured variable-parameter. The ideal value of MBE is ‘zero’ [12,13]. To illustrate the performance of the adaptive approach method, experimental results with Liner Prediction filter and adaptive approach method are compared in Table 1.

*Table 1. Experimental Results on solar radiation data of Van region, Turkey*

| | RMSE ($W/m^2$) | MBE ($W/m^2$) |
|---|---|---|
| Linear Prediction Filter | 104.23 | 8.97 |
| Adaptive Approach Method | 76.08 | 11.76 |

As seen in Table 1, adaptive approach method outperforms the Linear Prediction Filter according to RMSE criteria. Nearly 25% improvement on prediction performance is achieved by using adaptive approach method. MBE result with adaptive approach bigger than the linear prediction filter. This means adaptive approach method over predicts the observation and these predictions are generally greater than linear prediction filter's. However, overall estimations with adaptive approach method are better than the linear prediction filter. The correlations between the observed and predicted values are shown in Figure 3.

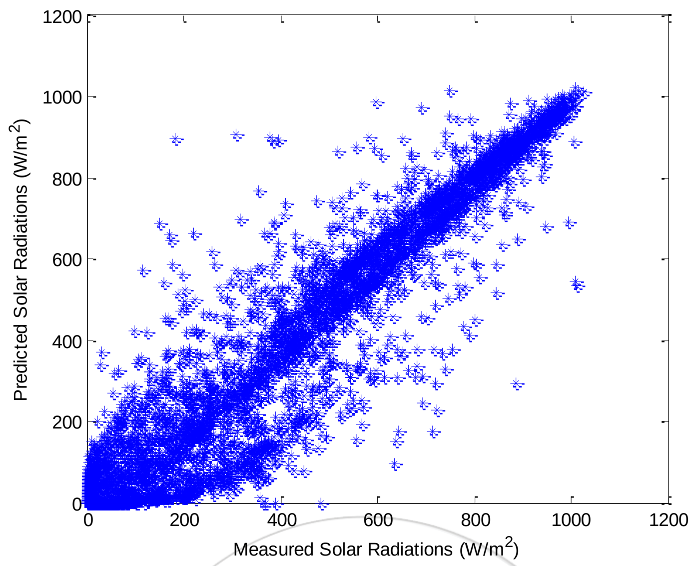


*Figure 3. Correlations between the observed and predicted data*

As seen in Figure 3, the predicted values are correlated with the observed values of solar radiation. The prediction results are closely matching observed data along the diagonal axis. The slope of the fit nearly $45^0$ and scatter is so narrow. These indicate a good prediction performance. Figure 4 illustrates the mesh plot of the prediction error. The error pixels are almost uncorrelated with each other. The uncorrelated samples indicate that the prediction almost totally exploits the predictable part of the data. Therefore, the model works with very good accuracy.

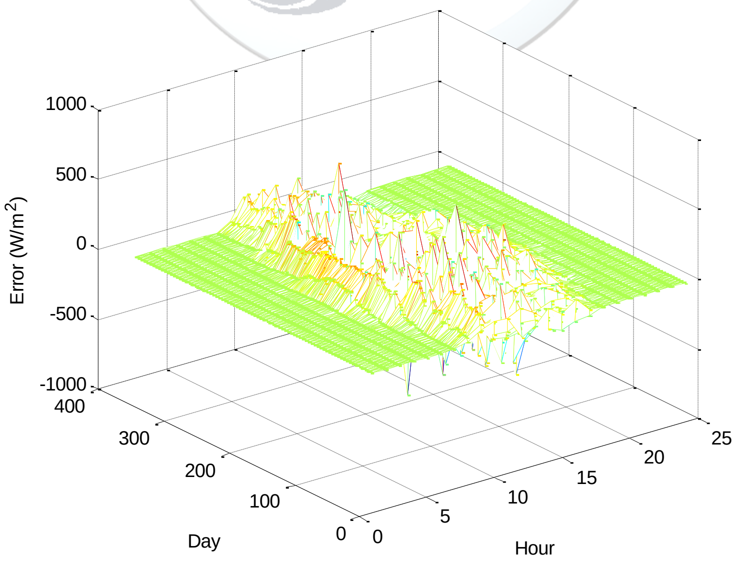


*Figure 4. Mesh plot of the prediction error with adaptive approach method*

## 5. CONCLUSION

The adaptive approach method is used in this study for hourly solar radiation modeling. adaptive approach method, combines linear prediction filter and an empiric model to improve the prediction performance. The selection of the model is managed by using actual clearness index value. The solar radiation data used in this study belongs to Van region of Turkey and measure in 1 year period from 1$^{st}$ Jan to 31$^{th}$ Dec 2014. To test the performance of the adaptive approach method, results are compared to results obtained with linear prediction filters. The experimental results show that the adaptive approach method outperforms the linear filter approach. The performance of different combining strategies with different filter templates and empiric models can be investigated as a future work.

## REFERENCES

[1]. K. Benmouiza and A. Cheknane, "Forecasting hourly global solar radiation using hybrid k-means and nonlinear autoregressive neural network models," Energy Convers. Manag., vol. 75, pp. 561–569, Nov. 2013.
[2]. J. R. Trapero, N. Kourentzes, and A. Martin, "Short-term solar irradiation forecasting based on Dynamic Harmonic Regression," Energy, vol. 84, pp. 289–295, May 2015.
[3]. Y. Kashyap, A. Bansal, and A. K. Sao, "Solar radiation forecasting with multiple parameters neural networks," Renew. Sustain. Energy Rev., vol. 49, pp. 825–835, Sep. 2015.
[4]. Y. Gala, Á. Fernández, J. Díaz, and J. R. Dorronsoro, "Hybrid machine learning forecasting of solar radiation values," Neurocomputing, vol. 176, pp. 48–59, May 2015.
[5]. M. Ghayekhloo, M. Ghofrani, M. B. Menhaj, and R. Azimi, "A novel clustering approach for short-term solar radiation forecasting," Sol. Energy, vol. 122, pp. 1371–1383, Dec. 2015.
[6]. L. Mazorra Aguiar, B. Pereira, M. David, F. Díaz, and P. Lauret, "Use of satellite data to improve solar radiation forecasting with Bayesian Artificial Neural Networks," Sol. Energy, vol. 122, pp. 1309–1324, Dec. 2015.
[7]. F. O. Hocaoğlu, Ö. N. Gerek, and M. Kurban, "Hourly solar radiation forecasting using optimal coefficient 2-D linear filters and feed-forward neural networks," Sol. Energy, vol. 82, no. 8, pp. 714–726, Aug. 2008.
[8]. E. Akarslan, F. O. Hocaoğlu, and R. Edizkan, "A novel M-D (multi-dimensional) linear prediction filter approach for hourly solar radiation forecasting," Energy, vol. 73, pp. 978–986, Aug. 2014.
[9]. E. Akarslan and F. O. Hocaoglu, "A novel adaptive approach for hourly solar radiation forecasting," Renew. Energy, vol. 87, pp. 628–633, Mar. 2016.
[10]. R. G. Allen, "Environmental, and E. Water Resources Institute," Task Comm. Stand. Ref. ASCE Stand. Ref. evapotranspiration equation. Reston, Va. Am. Soc. Civ. Eng., 2005.
[11]. N. Z. Al-Rawahi, Y. H. Zurigat, and N. A. Al-Azri, "Prediction of hourly solar radiation on horizontal and inclined surfaces for Muscat/Oman," J. Eng. Res., vol. 8, no. 2, pp. 19–31, 2011.
[12]. P. T. Nastos, A. G. Paliatsos, K. V. Koukouletsos, I. K. Larissi, and K. P. Moustris, "Artificial neural networks modeling for forecasting the maximum daily total precipitation at Athens, Greece," Atmos. Res., vol. 144, pp. 141–150, Jul. 2014.
[13]. K. P. Moustris, I. C. Ziomas, and A. G. Paliatsos, "3-Day-Ahead Forecasting of Regional Pollution Index for the Pollutants NO2, CO, SO2, and O3 Using Artificial Neural Networks in Athens, Greece," Water, Air, Soil Pollut., vol. 209, no. 1–4, pp. 29–43, Aug. 2009.