Table V. – Newly developed Tudela irradiation forecaster

PARAMETER	SUNNY	PARTIALLY CLOUDY	CLOUDY
RMSE	7.90	31.67	86.83
Error (%)	0.55	1.29	2.54

In addition, if the error distribution of both forecasters in Tudela throughout 2017 is compared, the results obtained with the new forecaster are better than with the original one. The accuracy for days with an error lower than 2% improves from 69% to 73% with the ensemble forecaster.

Finally, if the RMSE in Tables III and V, which are related to the ensemble forecaster, are compared with the results in the literature [4], [19], [23], it can be considered that the results obtained through this forecaster are similar to or better than other results obtained through different models. This improvement relies on the fact that the average of the forecasts made by different structures reduces the probability of less accurate predictions.

5. Conclusion

This paper presents a forecaster that is able to predict solar irradiation with a high standard of accuracy in a very short-term horizon, next 10 minutes. The results demonstrated that the predictions make with the ensemble forecaster (Figures 9 and 11, Tables II and V) equalled or surpassed the predictions of non-ensemble forecasters, even when they were found to be the optimal ones for each location, as seen in [17].

This improvement the accuracy relies on the fact that the ensemble forecaster is formed by two RNNs with different structures, and whose predictions are averaged to obtain a single forecast. The architecture of these RNNs are the most common structures obtained from applying the methodology summarized in this paper to two different Spanish locations. Finally, this tool can be integrated into microgrids with solar generators to reduce uncertainty.

References

[1] H.T. Yang, C.H. Ming, Y.C. Huang, and Y.S. Pai, "A Weather-Based Hybrid Method for 1-Day ahead Hourly Forecasting of PV Power Output", in IEEE Trans. Sustainable energy, Vol5, pp. 917-926, July 2014.

[2] A.K. Sahoo, and S.K. Sahoo, "Energy Forecasting For Grid Connected MW Range Solar PV System", in 7th India International Conference on Power Electronics (IICPE), 2016.

[3] I. Majumder, M.K. Behera and N. Nayak, "Solar Power Forecasting Using a Hybrid EMD-ELM Method", in International Conference on circuits Power and Computing Technologies (ICCPCT), 2017.

[4] A. Kaur, L. Nonnenmacher, H.T.P. Pedro and C.F.M. Coimbra, "Benefits of solar forecasting for energy imbalance markets", in Renewable Energy, Vol. 86, pp. 819-830, 2016.

[5] V. Sharma, D. Yang, W. Walsh and T. Reindl, "Short term solar irradiance forecasting using a mixed wavelet neural network", in Renewable Energy, Vol. 90, pp. 481-492, 2016.

[6] X. Qing and Y. Niu, "Hourly day-ahead solar irradiance prediction using weather forecasts by LSTM", in Energy, Vol. 148, pp. 461-468, 2018.

[7] M. Paulescu, E. Paulescu, P. Gravila and V. Badescu, "Weather Modeling and Forecasting of PV Systems Operation," Springer, pp. 17-42, 2013.

[8] F.M. Lopes, H.G. Silva, R. Salgado, A. Cavaco, P. Canhoto and M. Collares-Pereira, "Short-term forecast of GHI and DNI for solar energy systems operation: assessment of the ECMWF integrated forecasting system in southern Portugal" in Solar Energy, Vol. 170, pp. 14-30, 2018.

[9] E.B. Ssekulima, M.B. Anwar, A.A. Hinai and M.S. El Morursi, "Wind speed and solar irradiance forecasting techniques for enhances renewable energy integration with the grid: a review", in IET Renewable Power Generation, Vol. 10, pp. 885- 898, 2016.

[10] E. Lorenz, J. Kühnert and D. Heinemann, "Overview of irradiance and photovoltaic power prediction", in A. Troccoli, L. Dubus, S.E. Haupt (Eds.): 'Weather matters for energy', Springer, pp. 429-454, 2014.

[11] S. Pelland, J. Remund, J. Kleissl T. oozkeiand K. De Barbandere, "Photovoltaic and solar forecasting: State of the art", in IEA PVPS, Task 14, pp. 1-36, 2013.

[12] J. Boland, M. Korolkiewwicz, M. Agrawal and J. Huang, "Forecasting solar irradiation on short time scales using a coupled autoregressive and dynamical system (cards) model", Porc. Of the Australian Solar Energy Conf., Melbourne, pp. 6-7, 2012.

[13] H. Jiang and Y. Dong, "A nonlinear support vector machine model with hard penalty function based on glowworm swarm optimization for forecasting daily global solar irradiation", in Energy Conversion and Management, Col. 126, pp. 991-1002, 2016.

[14] S.X. Chen, H.B. Gooi, and M.Q. Wang, "Solar irradiation forecast based on fuzzy logic and neural networks", in Renewable Energy, Vol. 52, pp. 118-127, 2013.

[15] P.S. Loh, J.V. Chua, A.C. Tan and C.I. Khaw, "Data-driven short-term forecasting of solar irradiance profile", in World Engineers Submit – Applied energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference, WES-CUE 2017, 19-21 July 2017, Singapore.

[16] S. Haykin, Neural Networks and Learning Machines - 3rd ed., Upper Saddle River: Pearson Education, Inc., 2009.

[17] F. Rodríguez, A. Fleetwood, A. Galarza and F. Fontán, "Predicting solar energy generation through artificial neural networks using weather forecasts for microgrid control", in Renewable Energy, Vol. 126, pp. 855-864, 2018.

[18] S.A. Kalogirou, "Artificial neural networks in renewable energy systems applications: a review", in Renewable & Sustainable Energy Reviews, Vol. 5, pp. 373-401, 2001.

[19] A. Shakya, S. Michael, C. Saunders, D. Armstrong, P. Pandey, S. Chalise and R. Tonkoski, "Solar Irradiance Forecasting in Remote Microgrids Using Markove Switching Model", in IEEE Transaction on Sustainable Energy, Vol. 8, pp.895-905,2017

[20] H. Zhou, W. Xu, C. Xue, H.B. Cao, X. Gu and J. Wang, "A Short-Term Forecasting Model for Photovoltaic Plants Based on Data Mining", in 3rd IEEE International Conference on Computer and Communications, 2017.

[21] J. E. Dayhoff and J. M. De Leo, "Artificial neural networks", in Conference on Prognostic Factors and Staging in Cancer Management: Contributions of Artificial Neural Networks and Other Statistical Models.

[22] B. Sivaneasan, C.Y. Yu and K.P. Goh, "Solar Forecasting using ANN with Fuzzy Logic Pre-processing", in in World Engineers Submit – Applied energy Symposium & Forum: Low Carbon Cities & Urban Energy Joint Conference, WES-CUE 2017, 19-21 July 2017, Singapore.

[23] H. Sheng, J. Xiao, Y. Cheng, Q. Ni and S. Wang, "Short Term Solar Power Forecasting Based on Weighted Gaussian Process Regression", in IEEE Transactions on Industrial Electronics, Vol. 65, NO1, 2018.