Summary Report

Project Title: Development of Behind-the-Meter Photovoltaic (PV) Power Forecasting Method.

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Summary: This research was conducted as an undergraduate design project, where an undergraduate student registered for a design course (EECE 4991) in 2020 at the University of Memphis. The goal of the project was to propose a new method of assessing the available capacity and forecasting of behind-the-meter (BTM) solar photovoltaic (PV) system. There are hundreds of thousands of BTM solar PV installations across the USA which generate a substantial amount of electricity. These installations can provide an untapped reservoir of dispatchable resources that can be counted on to provide reliable grid services. The BTM load prediction and management can play a pivotal role for effective and reliable operation of the grid system. For these reasons, this research focuses on developing a machine learning based approach to estimate the PV capacity based on predicted temperature and solar irradiance. The machine learning algorithm explored in this research is a subtractive clustering-based adaptive neuro-fuzzy inference system (ANFIS) model. ANFIS is a way of implementing fuzzy inference systems in the framework of adaptive neural networks.

There are many meteorological factors involved in how much power a PV cell will generate: atmospheric temperature, cloud coverage, humidity, heating degree days, cooling degree days, solar irradiance, etc., are all variables affecting generated power. In this research, we used temperature and solar irradiance as input parameters, as these two measurements are easily obtainable and have a direct relation to solar panel power generation. The machine learning algorithm used to predict energy from these two parameters is the ANFIS model. In addition, data is clustered based on related values so a prediction can be tailored to each cluster. The subtractive clustering method is used to identify cluster centers, in which the likelihood of each data point defining a cluster center is calculated, then clusters are formed from the calculated likelihood and specified cluster influence range.

For modeling, four fuzzy inference systems were generated, all of which were Sugeno systems. The first did not have neural networks—it was simply a fuzzy inference system using the training input and output data, as well as subtractive clustering. The second had neural networks and used backpropagation as its optimization method. Backpropagation trains the neural network by making errors flow between neurons in the opposite direction of the information. This causes a change in the weights and links between nodes while simultaneously

minimizing errors using an optimization technique such as gradient descent method. The third had neural networks and used a hybrid optimization method, where parameters are determined by a combination of backpropagation and least-squares estimation. The fourth had neural networks, used back propagation as its optimization method, and had manually adjusted membership functions. A validation dataset was introduced to all fuzzy inference systems using neural networks, thus preventing overfitting.

The fuzzy inference systems had two evaluations: the first evaluated the system against the training input data, and the second evaluated the system against the testing input data. The root mean square error (RMSE) was calculated for both evaluations. The RMSE is defined as:

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}} \qquad (1)$$

where $\hat{y}$ is is the predicted energy output and y is the actual energy output. Each RMSE is normalized. The fuzzy inference system evaluated against the testing input data was then plotted against the testing output data.

Results: The proposed ANFIS method worked well in predicting the energy generation from the BTM PV system. As it can be seen in the results of figures 1 and 2, both the second and third fuzzy inference systems had the same RMSE when checked against the testing input data.

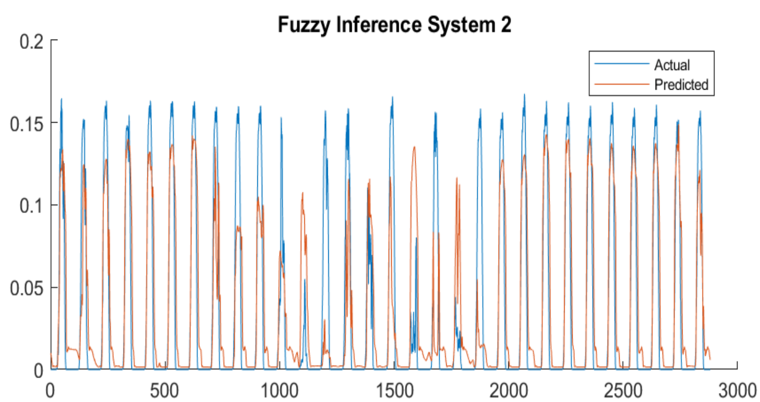

Fig. 1. Actual and predicted energy generation of the second fuzzy inference system.

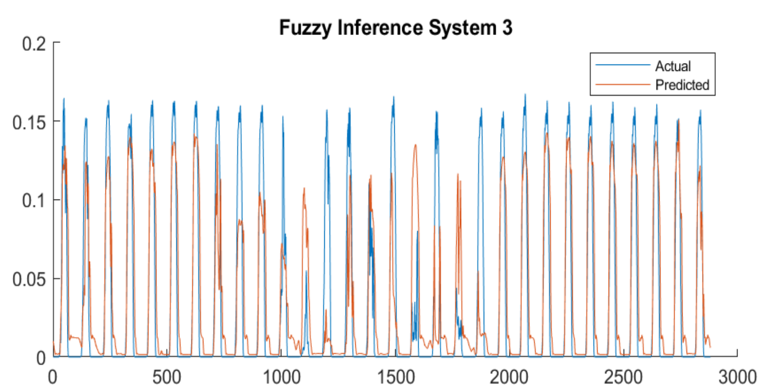

Fig. 2. Actual and predicted energy generation of the third fuzzy inference system.

In this work, the performance of the proposed subtractive clustering-based ANFIS in forecasting the available capacity of BTM PV has been compared with that of the regression model. Regression analysis is commonly used for determining strengths of predictors, forecasting an effect, and trend forecasting. As a result, it is often used in weather forecasting. For these reasons, we decided to use a regression model against our ANFIS model. We used three different regression models for our comparison: linear regression, regression trees, and regression ensembles. All of these models were generated in Matlab, and comparisons were made between models by observing RMSE values.

Linear regression is a modeling approach between one or more independent variables to one dependent variable. In this case, the independent variables are the solar irradiance and temperature, and the dependent variable is the amount of energy the solar panel would produce. Once the independent variables have been determined, linear regression can be applied to predict trends and outcomes. We applied linear regression to our training dataset and obtained the results listed in Table I. The results indicate the superiority of the proposed approach to the regression model.

Table I. Linear Regression Comparison

Model	RMSE
Fuzzy Inference 4	0.0344
Linear Regression	0.0471

Conclusion: A proper prediction model for BTM PV cells could benefit not only the owner of the solar panel, but also the society. Our research shows a subtractive clustering-based ANFIS model prediction has promise as a reliable solar forecasting method. Compared to other models such as regression analysis, our algorithm still remains robust. The proposed project will help assess the available capacity and forecast the BTM PV sources. The BTM load prediction and management will play an important role for effective and reliable operation of the grid system. Moreover, the proposed solution can be useful to electric power utilities.