ARIMA Model Selection for Energy Forecast

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Overview

PJM, a regional transmission organization, provides resources within the wholesale electricity market. Within the Appalachian Power Transmission Zone (AEP), there is a need to understand better energy transmission, measured in megawatts (MW) for this area. PJM collected hourly time series data from January 2016 to June 2023 and wants to develop a model to forecast energy usage in the future.

Our team was tasked with exploring PJM's energy transmission data and building 2 ARIMA forecast models to predict average monthly energy transmission (measured in MW). We first implemented time series decomposition and seasonally adjusted our dataset to do this. After concluding our data was non-stationary, we took the differences in our data and used ACF and PACF plots to develop ARIMA(0,1,1) and ARIMA(2,1,0) models. After evaluating these models and their performance forecasting the validation data, we tested their accuracy compared to the training data. The ARIMA(0,1,1) model achieved a mean absolute percent error (MAPE) of 2.11%, while the ARIMA (2,1,0) exhibited a MAPE of 2.54%. Given its more accurate performance and lower complexity, we recommend that PJM proceed with the ARIMA(0,1,1) model to predict monthly average energy transmission. We also recommend that PJM implement regular data updates to ensure the long-term accuracy of this model while exploring other techniques, such as seasonal ARIMA, that may be a better fit for their modeling needs.

Methodology

Data Used

PJM provided 66,455 hourly energy transmission data observations from January 2016 to June 2023. Each observation included eight variables corresponding to characteristics such as date, time, region, and load of energy transmission in megawatts per hour.

The dataset was summarized by monthly energy transmission in MW and split into training, validation, and testing datasets. The training data for initial data exploration and model construction included average monthly energy transmission from January 2016 to December 2022. The validation data was used for model selection and included from January to April 2023. Finally, the test data included energy transmission observations from May to July 2023 and was used to evaluate the accuracy of the forecasts for our ARIMA models.

Model Recalibration

As described above, we divided the monthly energy transmission data into training, validation, and testing datasets. We used the training data to construct multiple ARIMA models. Once we selected the best ARIMA models, ARIMA(0,1,1) and ARIMA(2,1,0), we incorporated the validation data into the training set. We recalibrated our models using all the January 2016 to April 2023 data. These updated models were used to calculate accuracy metrics when applied to the test data, including observations from May to July 2023.

Analysis

Data Exploration

Initial exploration of the training data suggested that energy consumption followed a seasonal pattern, confirmed using STL decomposition. Therefore, our team used the seasonal component identified by the STL decomposition to seasonally adjust the training data to reduce the effect of seasonality on our models. Next, we performed an Augmented Dickey-Fuller (ADF) test on the seasonally adjusted data, which allowed us to conclude the data was non-stationary. To resolve this issue, we took differences in our data, and a subsequent ADF test confirmed the stationarity of the differenced data. Therefore, our ARIMA models included a d-value of 1, which allowed us to model the stationary data.

Model Creation

Using the PACF and ACF graphs, our team selected two ARIMA models. The ACF plot had a single spike at lag 1, while the PACF plot had spikes at lags 1 and 2. We created Model 1, an ARIMA(0,1,1), and Model 2, an ARIMA(2,1,0). After fitting these models, we conducted a Ljung-Box test and concluded neither model had significant autocorrelation in its residuals. Additionally, we conducted a Shapiro-Wilk test, indicating that both models' residuals followed a normal distribution. Based on these tests, our models adequately captured the signal within the data, leaving only white noise in the errors.

Next, we tested the accuracy of our models against the validation data. To do this, we added the seasonal component we identified before modeling to the ARIMA forecasts for Models 1 and 2. Figure 1 shows the performance of Model 1 (ARIMA(0,1,1)), which achieved a MAPE of 6.46%. Figure 2 shows the performance of Model 2 (ARIMA(2,1,0)), which exhibited a MAPE of 7.44%.

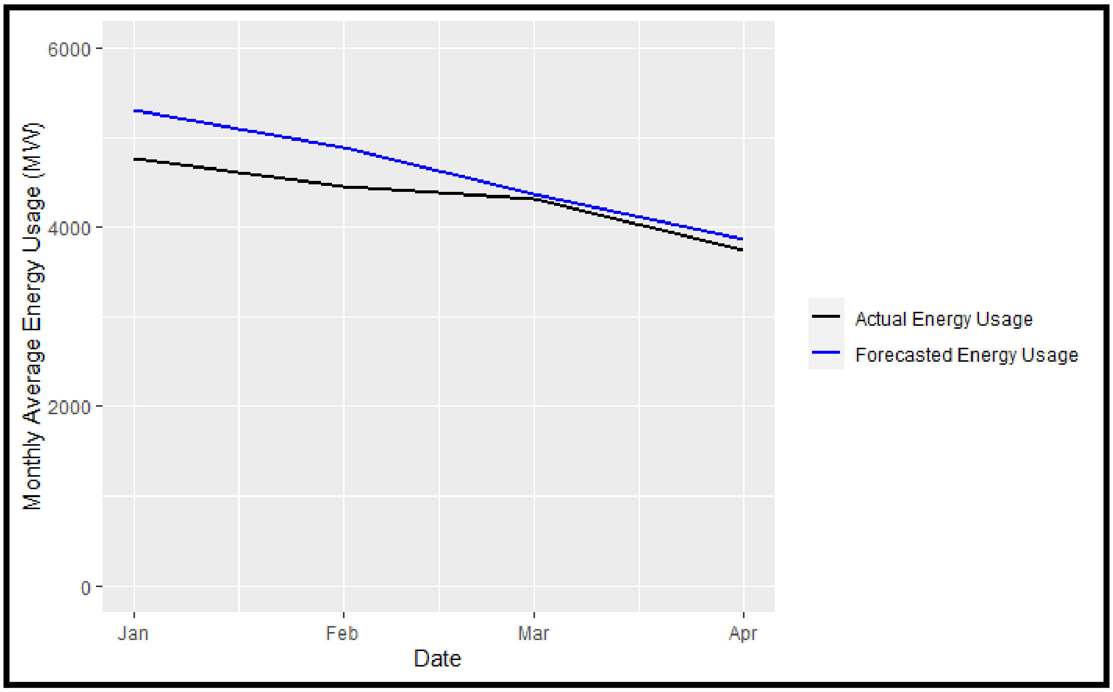

Figure 1: Model 1 - ARIMA(0,1,1): Actual Average Monthly Energy Usage (MW) Compared to Validation Forecast

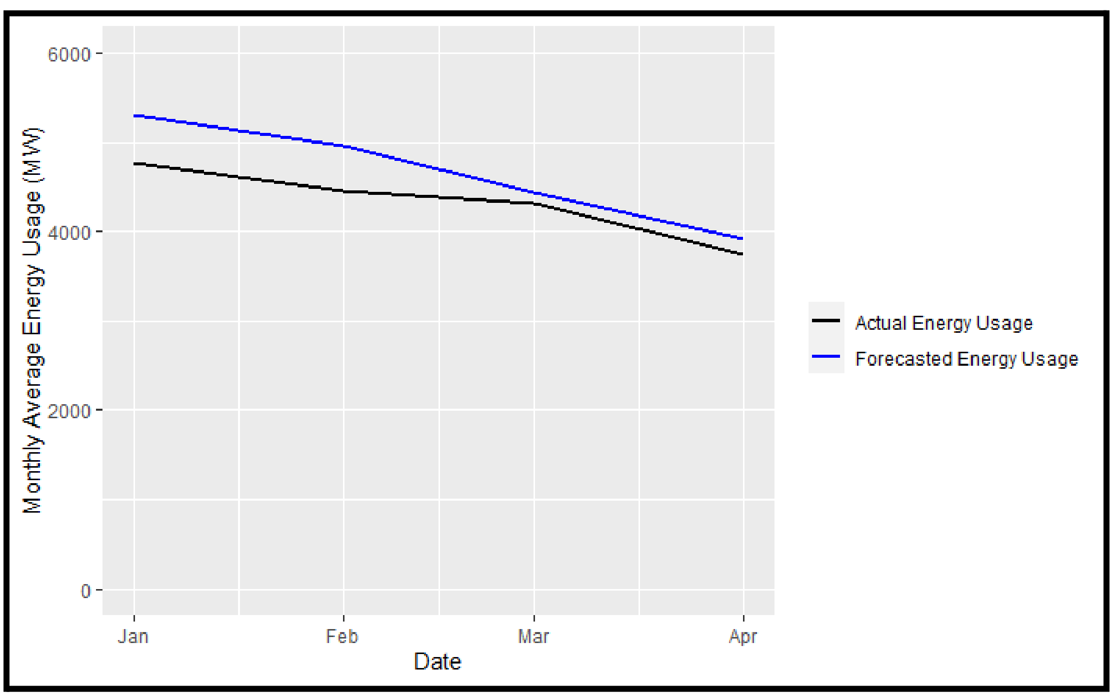

Figure 2: Model 2 - ARIMA(2,1,0): Actual Average Monthly Energy Usage (MW) Compared to Validation Forecast

Visually, the plots are very similar, indicating that the models made similar predictions. Regarding performance, Model 1 was slightly more accurate than Model 2, with a 1-point lower MAPE. Model 1 is also simpler than Model 2, with just one MA term, compared to 2 AR terms in Model 2. Otherwise, both models have normally distributed residuals without autocorrelation (indicated by the Ljung-Box and Shaprio-Wilk tests above), and both models appear to capture the signal within the data without a high degree of complexity.

Model Testing

Once we selected models, we re-incorporated the validation data into the training data and recalibrated the ARIMA models before testing. We used an identical process to adjust the updated training data seasonally. Our team generated forecasts for the test dataset, encompassing average monthly energy usage from May to July 2023.

Compared to the observed values in the test data, Model 1 (ARIMA(0,1,1)) achieved a MAPE of 2.11%, a 4.35-point reduction in error compared to its performance on the validation set. Similarly, Model 2 (ARIMA(2,1,0)) had a MAPE of 2.54%, a 4.9-point reduction in error. Figures 3 and 4 illustrate the proximity of the forecasted values for Models 1 and 2 compared to the observed monthly average energy transmission values. Both models performed better on the testing data than the validation data. However, considering it performed better on the validation and test data and its lower complexity, Model 1 (ARIMA(0,1,1)) is a more effective approach to forecasting monthly average energy transmission.

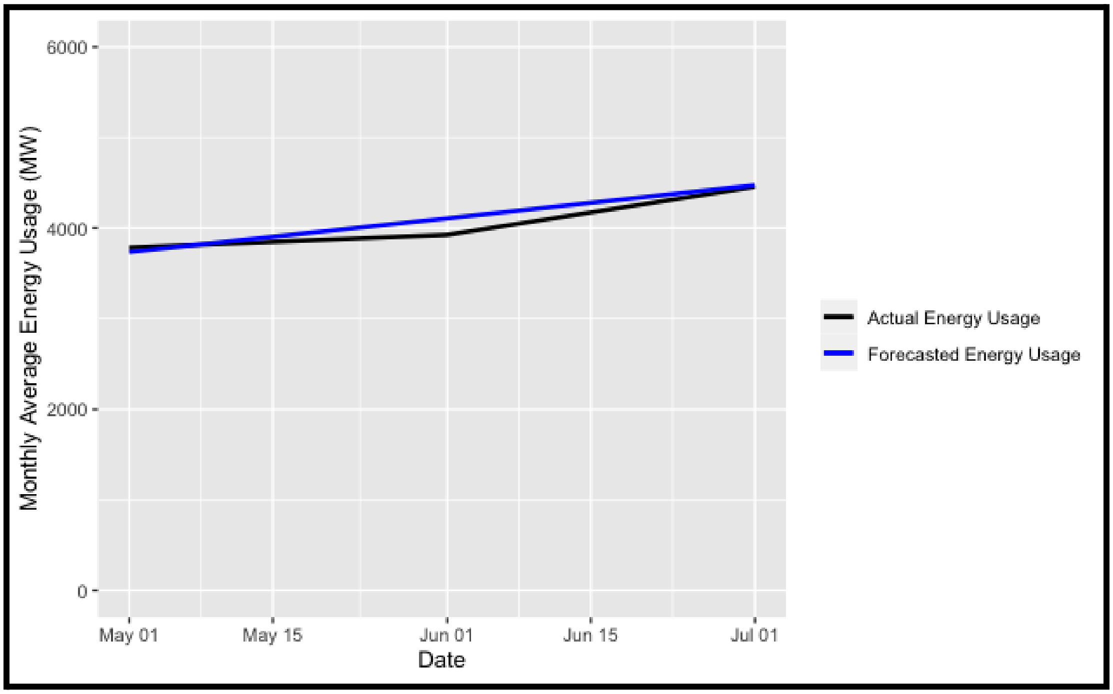

Figure 3: Model 1 - ARIMA(0,1,1): Actual Average Monthly Energy Usage (MW) Compared to Test Forecast

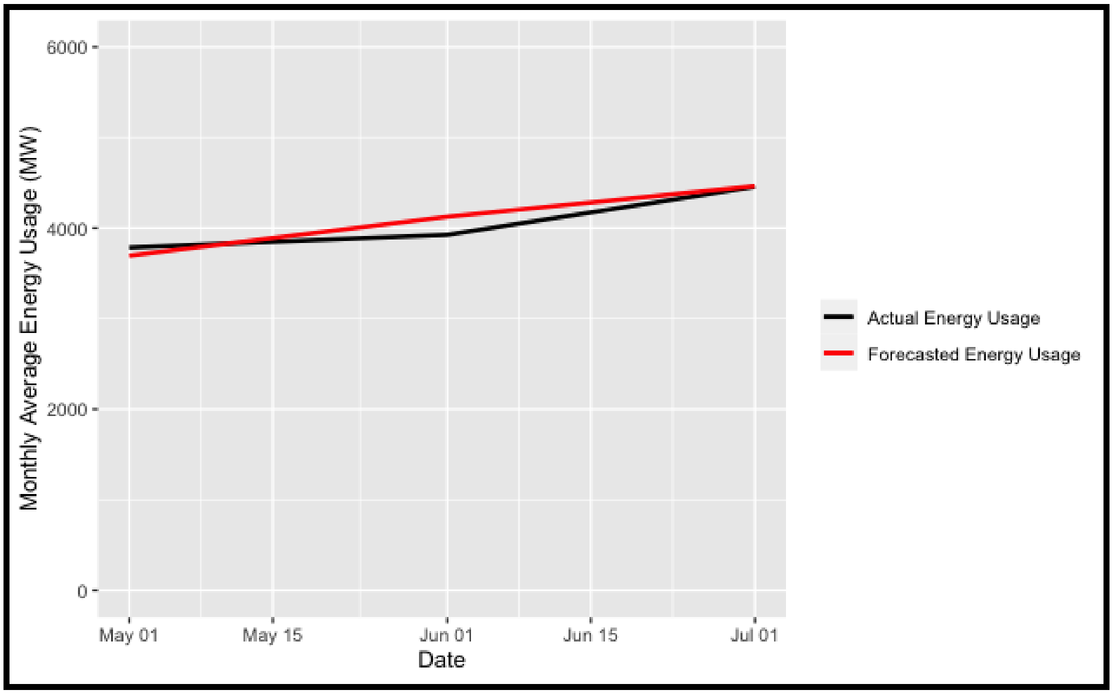

Figure 4: Model 2 - ARIMA(2,1,0): Actual Average Monthly Energy Usage (MW) Compared to Test Forecast

Results and Recommendations

In our analysis of energy forecasting for the AEP Appalachian Power Transmission Zone, we employed two ARIMA models: ARIMA(0,1,1) and ARIMA(2,1,0). After conducting data exploration and model creation, we observed that both models demonstrated satisfactory performance during the validation phase. Model 1 achieved a MAPE of 6.46%, and Model 2 attained a MAPE of 7.44%. Despite their simplicity, these models effectively captured the underlying data patterns, indicating their suitability for forecasting energy transmission. Upon recalibration using the validation data, we applied these models to the test dataset, encompassing energy usage from May to July 2023. Despite being a simpler model, Model 1 exhibited superior forecasting accuracy, yielding a MAPE of 2.11%, representing a significant improvement in accuracy compared to the validation phase. Model 2, while still performing well, produced a MAPE of 2.54%. These results indicate that Model 1 is the preferred choice for forecasting average monthly energy transmission in the AEP Appalachian Power Transmission Zone.

Building on our results, we recommend adopting Model 1 (ARIMA(0,1,1)) for PJM's energy forecasting needs in this region. To ensure the continued reliability and effectiveness of Model 1, we propose implementing regular model and data updates to account for evolving trends and shifts in energy usage patterns. Additionally, considering external factors that may influence energy demand in the region, such as economic conditions and weather data, is essential for more robust long-term forecasting tailored to PJM's goals and objectives. Exploring advanced modeling approaches and experimenting with seasonal ARIMA models can enhance forecasting accuracy, considering the high degree of seasonality in the data. These recommendations align with PJM's mission to provide reliable and efficient energy services to its customers.

Conclusion

To conclude, our team developed two ARIMA models to forecast energy transmission for the AEP Appalachian Power Transmission Zone. Both models performed well, but our team believes an ARIMA(0,1,1) is the best option to meet PJM's need for an accurate monthly average energy transmission model. We recommend that PJM proceed with this model but implement regular model and data updates to ensure the long-term quality of its predictions while exploring other analytical options, such as seasonal ARIMA, that may produce more accurate results.

Homework Report Checklist

Sections & Structure

Overview

AH,TL,GB,MK, SD	Is the overview concise?
AH,TL,GB,MK, SD	Does it provide context about the business problem? <Content>
AH,TL,GB,MK, SD	Does it briefly address your team's work, quantifiable results, and recommendations? <Action>
AH,TL,GB,MK, SD	Does it offer audience-centered reasons for recommendations? <Context>

Body Sections

AH,TL,GB,,MK, SD	Does the report body include information on methods, analysis, quantifiable results, and recommendations?
AH,TL,GB,MK, SD	Is content grouped into appropriate sections (*methodology*, *analysis*, *results*, *recommendations*)?

Conclusion

AH,TL,GB,MK, SD	Does the report have a conclusion?
AH,TL,GB,MK, SD	Does the conclusion sum up the report and emphasize relevant takeaways?

Structure

AH,TL,GB,MK SD	Does each major section have a heading?
AH,TL,GB,MK ,SD	Are sections, subsections, and paragraphs organized logically for easy navigation?

Visuals

Introduction, Discussion, and Captions

AH,TL,GB,MK, SD	Is each visual introduced in the text before it appears?
AH,TL,GB,MK, SD	Is each visual close to where it is introduced?
AH,TL,GB,MK, SD	Does each visual include a title with the following information: type (*table* or *figure*), number, and a descriptive caption?
AH,TL,GB,MK, SD	Is each visual discussed and interpreted in the text?
AH,TL,GB,MK, SD	Are figures and tables numbered separately?
AH,TL,GB,MK, SD	Are table captions above the table? Are figure captions below the figure?

Visual Design

AH,TL,GB,MK,SD	Do figures/tables use audience-friendly labels rather than variable names?
AH,TL,GB,MK,SD	Are the visuals easy to interpret?
AH,TL,GB,MK,SD	Are the visuals appropriately sized?
AH,TL,GB,MK,SD	Do tables appear on one page (*not split between 2 pages*)?
AH,TL,GB,MK,SD	Are legends and axis labels included for figures?
AH,TL,GB,MK,SD	Are numbers in tables right aligned?
AH,TL,GB,MK,SD	Are the visuals designed well (ex: *re-created in Word or Excel*, *not blurry or stretched*,…)?

Document Design

Title Page Design

AH,TL,GB,MK,SD	Does it include a descriptive title?
AH,TL,GB,MK,SD	Does it state the team name, team members' names, and the submission date?

Table of Contents Design

AH,TL,GB,MK,SD	Does it list all the major sections of the report with corresponding page numbers?
AH,TL,GB,MK,SD	Do the page numbers and sections in the Table of Contents match the report?

Document Design for Entire Report

AH,TL,GB,MK, SD	Is a standard typeface (*Calibri*, *Arial*, *etc.*) used?
AH,TL,GB,MK, SD	Is the size of the body text between 10-12 pt.?
AH,TL,GB,MK, SD	Are headings and subheadings used to organize information?
AH,TL,GB,MK, SD	Are distinctive text styles (*bold*, *italic*, *etc.*) used to distinguish between heading levels?
AH,TL,GB,MK, SD	Are text styles for headings used consistently (*ex: all level-one headings are bold*)?
AH,TL,GB,MK, SD	Are all paragraphs an appropriate length (*fewer than 12 lines*)?
AH,TL,GB,MK, SD	Is white space used to indicate paragraph breaks?
AH,TL,GB,MK, SD	Are bullet lists used for a series of items and numbered lists to show a hierarchy?

Writing Style and Mechanics

Spelling and Capitalization

AH,TL,GB,MK, SD	Are spelling errors located and corrected?
AH,TL,GB,MK, SD	Is spelling consistent throughout (*no switching between acceptable spellings*)?
AH,TL,GB,MK, SD	Is capitalization used appropriately (*proper nouns*, *etc.*)?
AH,TL,GB,MK, SD	Is capitalization of words consistent throughout the report?

Grammar and Punctuation

AH,GB,MK, SD	Are verb tenses used appropriately?
AH,GB,MK, SD	Are marks of punctuation used appropriately?
AH,GB,MK, SD	Is subject-verb agreement used in every sentence?
AH,GB,MK, SD	Is the grammar checker updated and are underlined grammar issues addressed?

Writing Style

AH,TL,GB,MK, SD	Are all sentences in the report easy for your audience to understand quickly?
AH,TL,GB,MK, SD	Are most sentences written in active voice?
AH,TL,GB,MK, SD	Are idioms and vague words eliminated from the report?
AH,TL,GB,MK, SD	Are acronyms introduced before being used?
AH,TL,GB,MK, SD	Are well-written topic sentences included at the beginning of each paragraph?
AH,TL,GB,MK, SD	Are lists parallel?
AH,TL,GB,MK, SD	Is the appropriate point of view used when addressing your audience or describing team actions?