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# Insights from PJM Interconnection's Exploration of Artificial Intelligence

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## SUMMARY

Recent technological advancements have thrust artificial intelligence (AI) into the spotlight, where it has alternately been heralded as a game-changer with endless potential or panned as a problematic tool that poses countless concerns. This paper seeks to provide a balanced view of the disruptive technology based on the experiences of PJM Interconnection, a regional transmission organization that operates the electric grid for all or part of 13 U.S. states and the District of Columbia.

PJM has been using forms of AI for some time but recently took a fresh look at these technologies given some of the new opportunities that recent innovations have presented. PJM formed a cross-functional team of senior technical staff, leaders and senior leaders to come up with a strategic approach that emphasizes learning and exploration in the AI space, with an eye towards the eventual development of a longer-term AI strategy. The approach combines an appropriate level of optimism about the potential value of AI with a tempered and diligent plan to explore prospective gains.

This paper outlines several insights gleaned from PJM's AI explorations to date. The company's experience with AI thus far indicates that while the technology does hold enormous potential, that potential will not be fully realized overnight. Five core needs are detailed in this paper that must be addressed to successfully deploy AI and sustain it long-term. The paper also highlights four lessons learned from PJM's experimentation with AI and delves into specifics of some of the use cases that yielded those lessons. It ends by noting additional AI opportunities that PJM is interested in exploring in the future.

## KEYWORDS

Artificial Intelligence, Machine Learning, Data and Analytics, Security

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## INTRODUCTION

Artificial intelligence (AI), the ability of a machine to simulate human intelligence, is not a new concept and has existed for decades in one form or another. Recently, however, accelerated technological innovations have brought AI to the forefront of public consciousness and inspired dialogue about how to apply the technology in new and exciting ways. AI systems can learn from data, identify patterns and make decisions without being explicitly programmed, which makes them well suited for a wide range of tasks and suggests that AI may be able to help grid operators adapt to the forces that are currently reshaping the electricity industry.

These forces, which include state decarbonization policies, intermittent resource growth, escalating retirements of thermal generation, changing load profiles and the proliferation of distributed energy resources, pose unique challenges to the industry that will require innovative solutions. AI may have a role to play in areas such as predictive maintenance, customer service support, demand forecasting, grid optimization, and the development of new products and services. AI also offers a great deal of promise when it comes to enhancing productivity, such as automating manual tasks to improve efficiency and free time for staff to focus on more critical endeavors.

Considering these factors, PJM Interconnection, a regional transmission organization (RTO) that operates the electric grid for all or part of 13 U.S. states and the District of Columbia, charged a cross-functional team with the development of a strategic approach to respond to the opportunities arising from AI. This approach, which looks out approximately 18 months, emphasizes learning and exploration and serves as a precursor to the creation of a longer-term AI strategy. Short- and medium-term tactics focus on laying a solid AI foundation and experimenting with ways that AI can drive value in alignment with PJM's strategic objectives.

This paper is intended to share some of PJM's learnings based on its experience with AI thus far. The first section, Foundations for AI Success, outlines some prerequisites for deploying and sustaining AI. The second section, Use Cases and Lessons Learned, highlights some of the key insights that PJM has gained through its experimentation with various AI use cases. The third section, Future Opportunities at PJM, lists additional use cases that PJM may wish to explore in the future as it continues its AI journey.

## FOUNDATIONS FOR AI SUCCESS

Given the vast possibilities that AI has to offer, it can be tempting to rush headlong into deployment of the technology. That said, PJM has found that there are core needs that should be addressed prior to embarking on an AI journey in order to establish a solid foundation for success. Five of these core needs are detailed below.

### Skill Development

AI is meaningless if a company's workforce does not possess the skills and capabilities needed to effectively utilize the technology. Ideally, an RTO's staff should combine an understanding of grid operations with strong technical expertise. Technical expertise includes both familiarity with new technology stacks as well as a solid grasp of data science, the latter of which is crucial to leverage the vast amounts of data that are continuously coming into RTOs. One important element, on the data side, is the ability to spot when data patterns begin to deviate from what has been seen in the past, as this may indicate that paradigm shifts are underway and historical norms/models may no longer hold true. This is especially important at present, when the electricity industry is undergoing massive changes on both the supply side (e.g., thermal resources being replaced by intermittent, renewable generation) and the demand side (e.g., load profiles changing as a result of data center growth, electrification and distributed resources).

In order to enhance its workforce's data and AI capabilities, PJM launched an "Analytics Academy" in 2023 in an effort to cultivate a strong foundation of data literacy and sharpen employees' advanced

analytical skills. The academy, an online learning platform for data literacy, tool use and decision-making training, is available to all employees regardless of their role within PJM. To date, more than 333 employees have invested in nearly 4,000 hours of learning on the platform.

Within Analytics Academy, PJM has implemented Communities of Learning, which provide PJM employees with a space to connect, learn and grow with one another on topics such as Python, SQL, DataBricks and Tableau/data visualization. These communities provide dynamic learning and growth environments where staff discuss topics, solve problems, ask and respond to questions, and solicit help with projects.

While the Analytics Academy is still in its relative infancy, PJM anticipates that employees' participation will yield long-term benefits such as increasing data literacy and building technical bench strength. The academy is also expected to promote a culture of continuous learning, foster innovation and improve employee morale and retention by affording development and growth opportunities. It is also anticipated to increase productivity and the standardization of methods and tools, as all participants will be working in similar languages and sharing their work and analysis with one another.

**Clear Vision and Expectations**

Before starting any AI project, it is important to ensure there is a clear vision for the endeavor. Management and project contributors should be able to articulate the reasons for pursuing the project, its expected benefits and what the outputs will be used for. They should also have a sense of what resources and data will be needed and be prepared to discuss compliance and ethical considerations. Additionally, management should have realistic expectations of what is and is not possible within the project; data literacy is essential to make sure leaders are asking the right questions and understand the caveats and limitations of any outputs of the models being used.

**Data Quality**

The foundation to effective analytics is good data. Biased data, inconsistent data, "noisy" data (i.e., data that includes errors or bad information) and outliers can all impact AI models and decrease the quality – and therefore the usability – of the outputs. A strong data governance framework is key to ensuring data quality, security and integrity. In recent years, PJM launched a data governance function whose goal, in part, was to address gaps in data quality. This included establishing organizational responsibility for data governance, founding a cross-functional team in charge of data oversight, managing enterprise-level metadata, and other governance- and quality-related efforts. Organizations that feel their data quality or data governance needs improvement would be well served by addressing these issues before committing heavily to AI investments.

**"Care and Feeding" of AI Models**

Over time, AI can experience "model degradation," which is a decline in performance as the assumptions and data on which the model was trained becomes less representative of the current data feeding the model. As paradigms change and relationships shift, previous assumptions may no longer be valid. One such example of this occurred during the COVID-19 pandemic, when coronavirus-related restrictions altered energy-use patterns; within PJM's footprint, weekday peak load declined by 10.4% on average between March and May of 2020 [1]. Regularly monitoring a wide range of metrics and identifying model performance drops can be challenging. It can also be hard to know when those drops require action. Because degradation can happen gradually over time, it can be difficult to determine the tipping point when it is necessary to fall to backup systems or retrain the model on updated data. Alarms and dashboards can assist, though they are only effective to the extent that staff and resources are available to address the degradation once it has been identified.

Feeding models new information can help to sustain them, but models that rely on real-time data require a complex setup to handle the volume of information that is coming in, as well as to validate that the data is high-quality. Noise is in all real data, and separating the noise from the signal is no easy task.

### Security and Risk Management

A number of risks exist in the deployment and usage of AI that must be planned for and managed. Given the importance of electricity to the economy, health and general well-being of society, mitigation of these risks is paramount. PJM and other electricity industry players may benefit from partnering with organizations – such as pharmaceutical companies or government organizations – in other sectors that face similar security concerns in order to learn from one another and share best practices. From a cybersecurity standpoint, some of the biggest risks include:

- *Limited acceptable third-party services:* PJM maintains confidential data, some of which may put critical infrastructure or the bulk electric system at risk if exposed. The need to ensure the confidentiality of this data impacts PJM's ability to use vendors and services that cannot demonstrate the ability to keep this data secure.

- *Lacking system security:* Underlying systems that run AI services must be protected in the same way as non-AI services. Good cyber hygiene practices, such as patching and network segmentation, are crucial.

- *Poor access management:* Controlling access to an AI system is critical given the variety of attacks that can be executed on it. Accounts with weak passwords that do not use multi-factor authentication can be compromised. Attacks can not only lead to data disclosure, but also to the degradation of model performance.

- *Information disclosure:* Confidential data housed within generative models can be exfiltrated through subversive techniques, including prompt engineering.

Beyond cybersecurity, it is also important to be mindful of business risks in the usage of AI. One such risk is lack of explainability. It can be difficult or impossible to explain the outputs of AI models produced from training data because there is not discrete code that produces deterministic outputs. Another potential issue is data poisoning attacks, which can manipulate a model through incorrect or compromised training data. Model accuracy will decrease, potentially leading to significant negative outcomes. In a similar vein, accidental or incidental bias in the data that is used to train a model can also lead to undesirable results.

## USE CASES AND LESSONS LEARNED

Up to this point, this paper has outlined a series of considerations and hurdles that will need to be worked through in order to successfully implement and sustain AI. This next section highlights three lessons learned from PJM's experimentation with AI thus far and describes some of the use cases that yielded those lessons.

### Lesson 1: Machine learning through crowdsourcing will only get an organization so far.

In 2019, PJM started a team for staff who wanted to explore machine learning in addition to their regular job responsibilities. The Machine Learning Team consisted of employees from a broad cross-section of the organization and relied on crowdsourcing to tap into a wide range of skills and knowledge. The members of the Machine Learning Team were passionate about AI, but because participation was voluntary, their "day jobs" necessarily took priority. Machine learning projects dragged on for years due to a lack of dedicated resources, and whenever a member of the team left the company, finding a replacement volunteer with similar skills and interest was difficult. Additionally, while management was supportive of the Machine Learning Team's creation, the team tended to be viewed as an "extracurricular" activity rather than a core part of participants' responsibilities at PJM. As a result, the participants were not officially evaluated on or held accountable for the work the team produced, which reduced incentives to drive forward progress.

*Example:*
One use case that was explored by the Machine Learning Team but never came to fruition was net interchange forecasting. Net interchange refers to the net amount of electric power exchanged between the service areas of different grid operators over a specified period of time. It is an important metric for managing the reliability and efficiency of the interconnected power grid, and forecasting net interchange helps grid operators ensure reliable power supply and grid stability by balancing load and generation. It also enables efficient resource allocation and cost optimization, leading to lower electricity prices for consumers.

The Machine Learning Team experimented to determine whether machine learning could increase the accuracy of PJM's net interchange forecast. Testing models revealed that XGBoost, a machine learning algorithm, performed exceptionally well in forecasting certain interfaces. The team's success with XGBoost demonstrated its potential as a tool, and a plan was made to put the model into production. Unfortunately, the Machine Learning Team had no dedicated staff to evaluate and maintain the XGBoost model. Due to this limitation, PJM had to terminate the project despite its initial success.

**Lesson 2: Begin with the end in mind.**

Working through various AI use cases has shown PJM the importance of keeping the end goal in mind from the outset. Management should clearly communicate what they are hoping to accomplish and build in checkpoints over the course of each experiment so that the team can evaluate whether they are on track to deliver the desired result. Management should also evaluate whether the company has the necessary resources, processes and infrastructure in place to make the expected results actionable. If the answer is "no," it may not be in the company's best interest to continue investing time, money and resources in the experiment.

*Examples:*
PJM's experiment with using AI in bidding behaviour analytics illustrates this point well. PJM's Financial Transmission Rights (FTR) Market allows participants to hedge against congestion costs in the electricity grid by purchasing rights to potential price differences across locations. After a PJM member defaulted on their FTR obligations, leading to significant financial losses, PJM decided to leverage burgeoning interest in machine learning to help monitor the market. The purpose of the project was to evaluate bidding behaviors to establish a "normal" baseline and identify outliers that might have adverse effects in the market. The team used anomaly detection to find outliers and created dashboards for analysts to review the findings.

The problems with this project were threefold. First, PJM lacked dedicated staff to continuously monitor the dashboards, relying solely on volunteers who were not always available. Second, fundamental changes in the FTR market data caused the visualizations to become inaccurate or non-functional, requiring constant updates and adjustments to the model that PJM was unable to manage with its limited resources. The third problem was that the results were not actionable. The anomalies identified in the bidding data only indicated that a particular portfolio or bid differed from the rest, without implying any malicious intent. This lack of actionable insights meant that the detection of anomalies did not translate into meaningful or practical interventions. When anomalies were detected, there was no established procedure or immediate action plan, which necessitated further investigation, slowed down the response time and reduced the effectiveness of the monitoring system.

A second PJM use case that ran into similar problems was nodal load analytics. An RTO can see aggregate load data because it manages the overall balance of electricity supply and demand across its footprint, focusing on the total or zonal load to ensure grid stability and efficiency. However, RTOs do not have insight into customer-level data and usage, as these granular details are typically managed by local utilities. This separation of data means that the RTO does not have visibility into the information that would be helpful to understand load patterns outside of the pricing node-level load itself.

The team used anomaly detection and could see anomalies appear as a storm moved across an area, visually highlighting disruptions in the data. However, this information was not actionable. While the anomalies indicated changes in the load patterns due to the storm, they did not provide specific guidance on how to respond or mitigate the impact, limiting the practical utility of the insights gained. For that reason, the project was ultimately discontinued.

**Lesson 3: AI does not eliminate the need for human judgment.**

While it can be tempting to view AI as a panacea thanks to its vast computational power, AI alone is not the answer to every complex problem. PJM's Control Center is staffed by a team of reliability engineers, master coordinators, meteorologists, generation dispatchers, master dispatchers and shift supervisors [2]. AI can be useful in helping this team make informed decisions quickly, automating routine tasks to free up dispatcher time, and predicting and mitigating the impact of extreme events. However, human oversight is still necessary. The electric grid is complex, and new scenarios can arise that the models have not seen previously. The human element is necessary when unforeseen issues occur that require high-level decision-making and judgement, especially during an emergency situation.

*Examples:*
PJM recently completed a research paper on the use of natural language processing to predict the energization of new transmission equipment [3]. PJM's current process to manually review outage tickets and determine whether new equipment is being energized is error-prone and time consuming. The paper proposed using machine learning models to automate this process, with a focus on how to handle the data imbalance that is caused by the low number of tickets that include energizations. After cleaning and encoding the textual data, both traditional and deep learning algorithms were used to classify tickets. The results showed that, relative to the other algorithms, XGBoost provided the best trade-off between false positives and false negatives. Unfortunately, the process was too complex and required too much pre-processing to put into production. As noted in the research paper, "The cut-in prediction problem involves extensive text pre-processing and word tokenization followed by the use of ML algorithms for classification" [3]. Different pre-processing was required for different companies that submitted outage tickets, which introduced the potential for discrimination and bias. PJM ultimately decided that the critical process to determine equipment energization should continue to rely on human judgment.

Another PJM use case was the subject of a recent research paper on the use of a machine learning based clustering algorithm, DBSCAN, to improve the current practices related to manual load shedding directives [4]. During a derecho storm in 2022, PJM directed American Electric Power (AEP) to implement pre-contingency load shedding due to the elevated risk of cascading outages. PJM's tools and procedures are geared towards the typical single-contingency single-constraint problem; in the 2022 AEP case, however, there were 16 transmission outages, 10 contingencies and multiple constraints. The paper proposes a methodology that improves upon the current practices by (a) optimizing the amount of load shed needed to jointly relieve multiple constraints and prevent cascading failures, and (b) using machine learning to generate alternative distribution feeder options to achieve the desired load shedding relief. Although the validation and tests of the proposed methodology were successful, a recent internal discussion suggested that if this methodology were to be implemented, operator verification would still be needed before issuing the load shed plan to any transmission owner.

**Lesson 4: Consider starting with smaller AI productivity-enhancing initiatives.**

While energy specific AI solutions could have a significant impact on utilities and the industry, improving reliability tools, "smaller" AI solutions that enhance productivity could provide marginal benefits with much less effort.

*Example:*
PJM is governed by several manuals as well as a Tariff and Operating Agreement. These documents are extensive, and it can be difficult to pinpoint information within them. Typically, staff would consult

subject matter experts to quickly find related information in the documents. To address this challenge, PJM conducted a pilot project using Microsoft Copilot Studio. PJM uploaded its public manuals, Tariff and Operating Agreement into Copilot Studio and then rolled out a chatbot to a subset of pilot users at PJM to evaluate Copilot Studio's effectiveness and accuracy in searching for information across those documents. After testing the chatbot over several months, PJM found that, although the solution is not perfect, it has the potential to significantly enhance staff productivity. PJM learned that conversational AI can provide users with a more simplified and natural way to find information easily and quickly across multiple sources while alleviating the number of requests to subject matter experts.

This work shows that starting with smaller AI initiatives can allow organizations to test and refine solutions with minimal risk and investment. These smaller projects can provide valuable insights and pave the way for more extensive AI implementations in the future, ultimately driving greater efficiency and innovation.

## FUTURE OPPORTUNITIES AT PJM

While PJM has gained many insights from its experimentation with AI, the work done up to this point is only the beginning. PJM will continue to explore new ways to apply AI and recently began discussions with a vendor on opportunities to improve its Day-Ahead Market solution and solve times. PJM is also working on analysis surrounding load forecasting and machine learning and plans to continue this endeavor [5,6]. Other areas that PJM is interested in exploring in the future include cybersecurity behavioral analytics, assisted coding, grid visualization, potential new horizons with phasor measurement units, and predictive analytics to support PJM's markets, operations and planning functions.

## CONCLUSION

PJM's experience to date indicates that while AI holds enormous potential, that potential will not be realized overnight. The insights outlined in this paper represent only a few of the considerations that will need to be worked through in order for the electricity industry to reap the full benefits of AI. PJM looks forward to continuing its journey of learning and experimentation and welcomes opportunities to engage with others along the way.

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