Building a Resilient and Sustainable Grid: A Study of Challenges and Opportunities in AI for Smart Virtual Power Plants

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Outline

- INTRODUCTION
- BACKGROUND
- CHALLENGES IN EXISTING VIRTUAL POWER PLANTS
- OPPORTUNITIES WITH AI FOR SMART VPPS
- RELATED WORK
- CONCLUSION

Introduction

Purpose of VPPs

Transformation from Traditional Power Plants to VPPs

The Rise of Renewable Energy in VPPs

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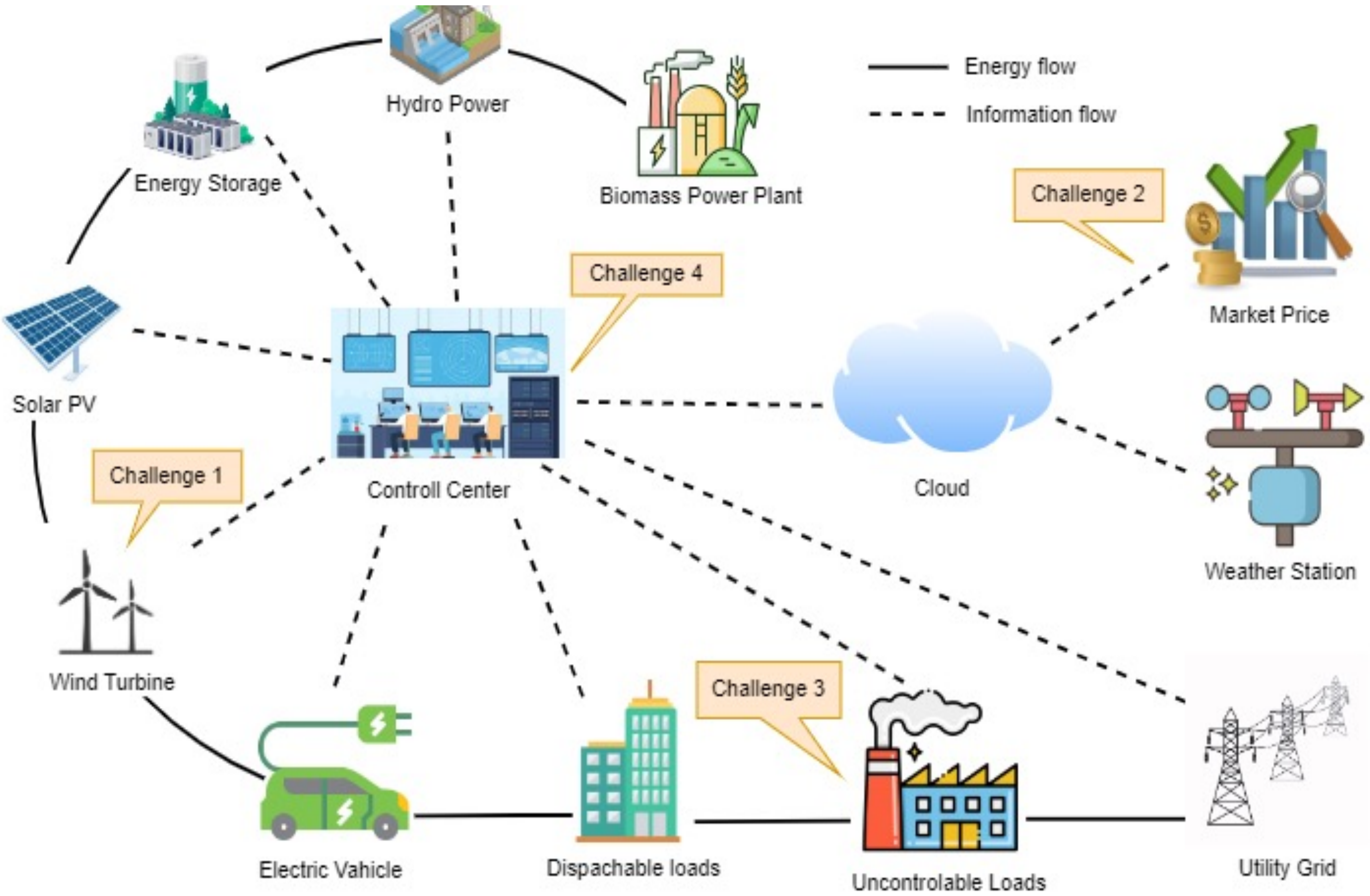
What is Virtual Power Plant



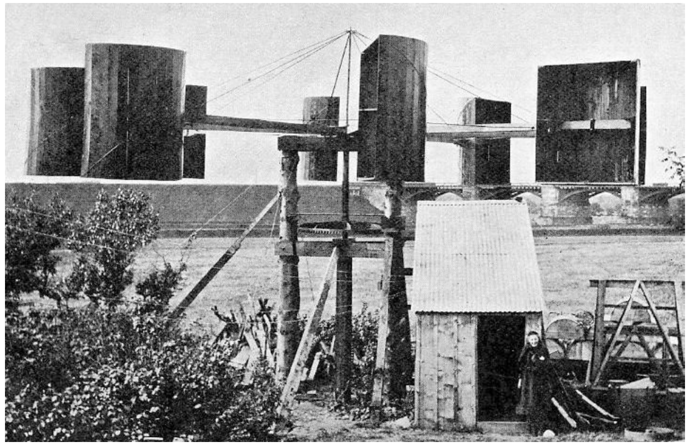
How VPP Works

DIVERSE ENERGY RESOURCES INTEGRATION

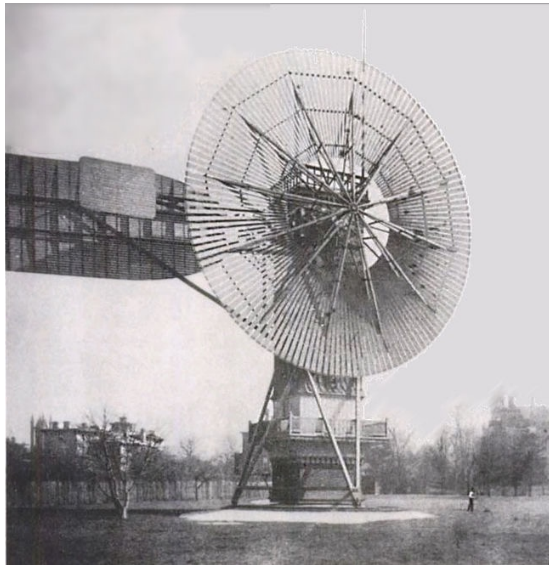
ADVANCED COMMUNICATION NETWORK

CONTROL SYSTEM FOR EFFICIENT MANAGEMENT

History and Evaluation



2018	AI in control, worldwide popularity
2009	Next Kraftwerke, Kiwi Power started operating VPP
2003	Smart Grid Technology
1997	Dr. Shimon Awerbuch's Proposal of VPP Concept in 1997
1982	First photovoltaic megawatt-scale power station
1945	The first practical silicon solar cell (Bell Lab)
1941	Wind Turbine supplied AC power to the electric grid
1913	First solar power plant
1887	The first wind turbine used for the production of electricity



Case Study

VPP Project	Location	Key Features	Capacity and Impact
Tesla's Suburban VPP	South Australia	- Utilizes distributed energy resources - Improves grid resilience - Connects Tesla Powerwall batteries in residences - Provides grid stabilization and backup power during outages	- 250 MW of solar energy production - 650 MWh of storage capacity
TEPCO's VPP	Tokyo, Japan	- Enhances energy security post-Fukushima disaster - Integrates rooftop solar, battery storage, EV charging - Achieves demand response, peak shaving - Provides backup power in emergencies	- Rooftop solar power facilities with a total capacity of 100 MW
Centrica's VPP	UK, Belgium, Multiple Countries	- Aggregates various renewable energy sources - Utilizes advanced control systems and real-time monitoring - Features 140 lithium-ion batteries at Terhills Leisure Park	- Total capacity of 32 MW - Contributes to grid stability and emission reduction

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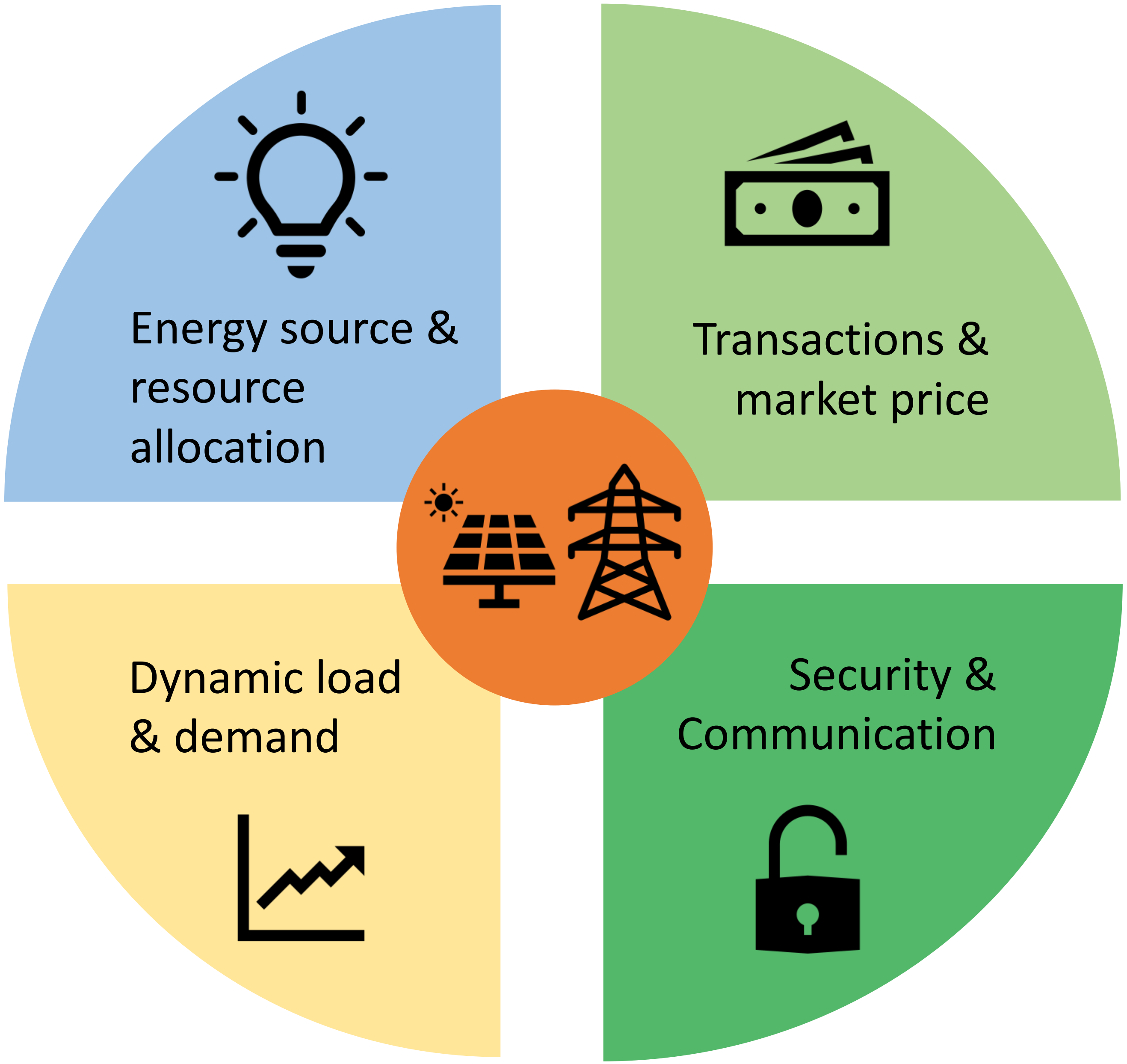
CHALLENGES IN EXISTING VIRTUAL POWER PLANTS



Energy Source and Resource Allocation

Growing Share of Renewable Energy in VPPs

- Wind power generation unpredictability is mainly due to stochastic variations in wind speed
- Wind and solar power generation forecasts exhibit notable margins of error, typically ranging from 20% to 30%.

Insufficient Energy Storage Capacity

- The effectiveness of these storage systems depends on factors like chemical composition, battery life, etc.
- Comprehensive consequences of integrating energy storage devices into VPPs are not yet fully explored.

Difficulties in Integrating with Existing Grids

- The adoption of distributed renewable energy sources has introduced significant unpredictability impacting the security, stability, and economic performance of the current power grid.
- The effective integration of these resources into the existing grid, mitigating their intermittency and volatility, and coordinating diverse energy storage systems and load conditions represent significant challenges.

Transactions and Market Price

Massive Trading and Real-time Prices

- Volatility in Energy Markets
- Impact of Renewable Energy on Trading

Regulatory Complexities Across Diverse Markets

- Variations influenced by changes in global markets and local policies
- Understanding of local and national energy policies and regulations is imperative to ensure regulatory compliance while optimizing transactions and fostering revenue growth

Strategic Operation Optimization and Risk Management

- Boost profits by purchasing energy at lower cost and selling them at higher prices
- Financial Stability and Sustainability

Dynamic Load and Demand

Load and Demand Uncertainty in VPPs

- Varies with seasonal changes
- Influenced by consumer habits, financial conditions, and emergencies

Uncontrollability of Grids Due to Load Variability

- variability in load demand poses significant challenges to the controllability of VPPs
- rise in electric vehicle use has increased unpredictability

Impact of Diverse Consumer Behaviors on Energy Demand

- various lifestyle choices and household activities
- areas with high electric vehicle usage see increased peak loads

Communication and Security

Data Transmission and Information Aggregation in VPPs

- Essential for managing and controlling distributed energy

Cybersecurity and Privacy Protection Challenges

- The collection and analysis of substantial energy data expose VPPs to data security and privacy risks.

Data Interoperability and IoT Integration

- Achieving interoperability across diverse systems and equipment from different manufacturers is technically challenging

Outline

Tackling Unstable Energy and Inefficient Resource

Use of algorithms like LSTM and simulated annealing for accurate predictions of solar and wind power[1,2]

AI improves energy storage systems in VPPs by using past data and load forecasts[3]

A novel deep reinforcement learning algorithm minimizes operating costs in off-grid VPPs by optimizing battery storage and flexible loads, with fossil fuel generators as backup [4]

Analyzing Market Fluctuations and Adapting to Regulatory Changes

- Predictive models constructed using AI analyze historical market data to forecast energy market prices[5]
- Natural language processing (NLP) for extracting key information from regulatory filings and automatic adjustment of VPP operations[6]
- Multi-agent reinforcement learning (MARL) approach in power producers' bidding strategies to achieve market equilibrium[7]

Overcoming Uncertainties and Better Understanding Consumers

AI technology for efficient and accurate balancing of supply and demand in response to electricity demand forecasting challenges[8]

Machine learning models for understanding household electricity consumption behavior and response[9]

Reinforcement learning for enhanced power grid control in extreme situations like large-scale blackouts[10]

Facilitating Effective Communication with Robust Security Measures

Novel method aimed at enhancing two-way communication within VPPs for ensuring efficient and reliable communication between the different components of a VPP[11].

Security architecture grounded in edge intelligent computing to mitigate risks, enhance system security, and ensure privacy and data protection[12].

Real-time intelligent energy management model for VPPs that enhance data interoperability through multi-objective, multi-level optimization strategies, facilitating real-time coordination among various energy resources[13].

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Related work

Academic Explorations in AI for Smart VPPs

- uncertainties of VPPs, including renewable energy resources, market price, and load uncertainty[11].
- enhancing day-ahead thermal and electrical scheduling[14]
- Mixed-Integer Linear Programming (MILP) models for maximizing VPP profits[15]

Industrial AI Effort for Smart VPPs

- Evergen developed a Distributed Energy Resource Management System (DERMS) that integrates Distributed Energy Resources (DERs) to advance renewable energy[16]
- H Energy's cloud platform, DERShare, manages numerous DERs, incorporating big data processing and real-time optimization in a VPP context[16]

Conclusion

The paper examines the concept, development, and components of Virtual Power Plants (VPPs), focusing on the challenges and opportunities presented by the application of AI in smart VPPs.

It details how AI enhances the performance, efficiency, economics, and sustainability of VPPs by optimizing energy sources, managing transactions and market dynamics, accommodating dynamic loads and demands, and enhancing communication and security protocols.

Reference

1. Muhammad Muneeb. 2022. LSTM Input Timestep Optimization using Simulated Annealing for Wind Power Predictions. Plosone (2022)
2. Meftah Elsaraiti and Adel Merabet. 2022. Solar Power Forecasting using Deep Learning Techniques. IEEE Access (2022)
3. 2021. How AI and Software Are Transforming Virtual Power Plants. https://www.stem.com/how-ai-and-software-transform-virtual-power-plants/
4. Mostafa Shibl, Loay Ismail, and Ahmed Massoud. 2021. Electric Vehicles Charging Management Using Machine Learning Considering Fast Charging and Vehicle-to-Grid Operation. Energies 19 (2021)
5. 2023. Daily Electricity Price Forecasting Using Artificial Intelligence Models in the Iranian Electricity Market. Energy (2023)
6. Heiko Thimm. 2023. Data Modeling and NLP-based Scoring Method to Assess the Relevance of Environmental Regulatory Announcements. Environment Systems and Decisions (2023)
7. Dehai Yang, Yong Wei, Xuelei Nie, Liqiang Zhao, and Guiyang Xu. 2023. Reinforcement Learning-Based Market Game Model Considering Virtual Power Plants. In 2023 5th International Conference on Power and Energy Technology (ICPET). IEEE
8. Isaac Kofi Nti, Moses Teimeh, Owusu Nyarko-Boateng, and Adebayo Felix Adekoya. 2020. Electricity Load Forecasting: A Systematic Review. Journal of Electrical Systems and Information Technology (2020).
9. Sambeet Mishra, Chiara Bordin, Madis Leinakse, Fushuan Wen, Robert J Howlett, and Ivo Palu. 2022. Virtual Power Plants and Integrated Energy System: Current Status and Future Prospects. Handbook of Smart Energy Systems (2022).
10. Zhenting Zhao, Po-Yen Chen, and Yucheng Jin. 2022. Reinforcement Learning for Resilient Power Grids. arXiv preprint arXiv:2212.04069 (2022).

Reference

11. Mohammad Mohammadi Roozbehani, Ehsan Heydarian Forushani, Saeed Hasanzadeh, and Seifeddine Ben Elghali. 2022. Virtual Power Plant Operational Strategies: Models, Markets, Optimization, Challenges, and Opportunities. Sustainability (2022).
12. Sampath Kumar Venkatachary, Annamalai Alagappan, and Leo John Baptist Andrews. 2021. Cybersecurity Challenges in Energy Sector (Virtual Power Plants)-Can Edge Computing Principles be Applied to Enhance Security? Energy Informatics (2021
13. Jannat Ul Ain Binte Wasif Ali, Syed Ali Abbas Kazmi, Abdullah Altamimi, Zafar A Khan, Omar Alrumayh, and M Mahad Malik. 2022. Smart Energy Management in Virtual Power Plant Paradigm with a New Improved Multilevel Optimization Based Approach. IEEE Access (2022)
14. Marco Giuntoli and Davide Poli. 2013. Optimized Thermal and Electrical Scheduling of a Large Scale Virtual Power Plant in the Presence of Energy Storages. IEEE Transactions on Smart Grid (2013)
15. Marko Zdrilić, Hrvoje Pandžić, and Igor Kuzle. 2011. The Mixed-Integer Linear Optimization Model of Virtual Power Plant Operation. In 2011 8th International Conference on the European Energy Market (EEM). IEEE, Zagreb, Croatia
16. 5 Top Virtual Power Plant Solutions. https://tinyurl.com/3wvz236z


Questions?