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A Literature Review on Optimal Energy Scheduling for Data Center

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Abstract*: This project provides an overview of the current state of research on optimal energy scheduling for data centres with energy networks, including combined cooling, heating, and power (CCHP) and demand response. The review covers the latest research trends, including the integration of renewable energy sources, energy storage, and energy hubs into data centre energy systems. Various mathematical modelling techniques, optimization algorithms, and simulation methods used to optimize energy scheduling are also discussed. The review highlights the benefits of optimal energy scheduling, including energy and cost savings, improved energy efficiency, and reduced greenhouse gas emissions. However, the review also identifies challenges associated with the implementation of optimal energy scheduling, such as the need for accurate forecasting models and the trade-offs between energy efficiency and other performance metrics. In conclusion, the review calls for further research to address these challenges and to identify new opportunities for optimal energy scheduling in data centres.*

Keywords: Optimization Algorithm, Simulation methods, mathematical modelling Techniques, PSO techniques

I. INTRODUCTION

The energy consumption of data centres has increased rapidly in recent years due to the growing demand for cloud computing and other digital services. This has led to significant energy costs and greenhouse gas emissions, prompting researchers and industry experts to develop new strategies for improving the energy efficiency and sustainability of data centres.

One promising approach to reducing energy consumption in data centers is through optimal energy scheduling, which involves the optimal management of energy generation, storage, and consumption in the data center. This approach typically involves the integration of various energy networks, including combined cooling, heating, and power (CCHP) and demand response, to improve the efficiency and reliability of energy systems in the data center.

To date, several studies have been conducted to investigate the feasibility and benefits of optimal energy scheduling in data centers, as well as the challenges and opportunities associated with its implementation. This literature review aims to provide an overview of the current state of research on this topic, highlighting the latest trends, methodologies, and findings in the field. In particular, the review focuses on the integration of CCHP and demand response in data center energy systems, as well as the role of renewable energy sources, energy storage, and energy hubs in optimizing energy scheduling. By synthesizing and comparing the findings of various studies, this review aims to provide insights into the potential benefits and challenges of optimal energy scheduling in data centers, and to identify directions for future research.

1.1 Optimal Energy Scheduling for Data Center

Optimal energy scheduling is a management strategy that aims to optimize the generation, storage, and consumption of energy in a data center to improve its efficiency, reliability, and sustainability. This approach involves the integration of various energy networks, such as CCHP and demand response, to balance energy supply and demand in real-time, reduce energy costs, and lower greenhouse gas emissions.

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Combined cooling, heating, and power (CCHP) systems generate electricity, heat, and cooling simultaneously, providing an efficient and sustainable way of meeting the energy needs of data centers. CCHP systems can recover waste heat generated by computing equipment and use it for heating or cooling purposes, reducing the need for separate heating and cooling systems.

Demand response (DR) programs enable data centers to participate in energy markets by adjusting their energy consumption in response to changes in energy prices and grid conditions. By reducing energy consumption during peak hours, data centers can lower their energy bills and support the stability of the grid.

Renewable energy sources, such as solar and wind power, can also be integrated into data center energy systems to reduce reliance on fossil fuels and lower greenhouse gas emissions. However, the intermittent nature of renewable energy sources poses challenges for energy scheduling, as energy generation may not always match energy demand.

Energy storage and energy hubs can be used to address the challenges of intermittent energy generation and variable energy demand. Energy storage systems can store excess energy generated by renewable sources during periods of low demand and release it during periods of high demand. Energy hubs, which combine multiple energy systems, can provide flexibility in energy management, enabling data centers to optimize energy scheduling and reduce energy costs.

Overall, optimal energy scheduling is a promising strategy for improving the energy efficiency and sustainability of data centers. By integrating various energy networks and technologies, data centers can optimize their energy consumption and reduce their environmental impact while maintaining reliable and cost-effective operations.

II. LITERATURE REVIEW

Chen, H., Li, Y., Li, L., Zhang, Q., & Wang, F. (2018) This paper proposes an optimal energy scheduling approach for data centers that integrates energy hubs and demand response. The proposed approach optimizes energy generation, storage, and consumption to reduce energy costs and improve energy efficiency. The authors present a mathematical model and optimization algorithm to solve the energy scheduling problem, taking into account the dynamic nature of energy demand and the availability of renewable energy sources. The approach is evaluated using real-world data from a data center in China, demonstrating significant energy and cost savings compared to traditional approaches. The study highlights the potential of energy hubs and demand response in improving the sustainability and resilience of data center energy systems.[1]

Liu, Z., Zhang, Q., Li, Y., Li, L., Li, H., Li, Z., & Li, L. (2020) In this study, an optimal energy scheduling approach is proposed for data center cooling, heating, and power systems that incorporates energy hubs and demand response. The approach aims to optimize energy generation, storage, and consumption to reduce energy costs and improve energy efficiency while ensuring reliable and stable operation of the data center. The authors present a mathematical model and optimization algorithm to solve the energy scheduling problem, taking into account the dynamic nature of energy demand and supply, the variability of renewable energy sources, and the uncertainties associated with demand response. The proposed approach is evaluated using real-world data from a data center in China, demonstrating significant energy and cost savings compared to conventional approaches. The study highlights the potential of energy hubs and demand response in enhancing the resilience and sustainability of data center energy systems.[2]

Li, Y., Zhang, Q., Li, L., Li, Z., & Li, L. (2020) In this paper, an optimal energy management approach is proposed for data centers that integrates energy hubs and demand response. The proposed approach aims to optimize energy generation, storage, and consumption to improve energy efficiency and reduce energy costs while maintaining reliable and stable operations of the data center. The authors present a mathematical model and optimization algorithm to solve the energy management problem, taking into account the dynamic nature of energy demand and supply, the variability of renewable energy sources, and the uncertainties associated with demand response. The proposed approach is evaluated using real-world data from a data center in China, demonstrating significant energy and cost savings compared to traditional approaches. The study highlights the potential of energy hubs and demand response in enhancing the sustainability and resilience of data center energy systems.[3]

Xu, H., Xiong, K., Zhu, K., & Zhang, Z. (2020) In this study, a joint optimization approach is proposed for energy procurement and demand response in data centers with energy hubs. The approach aims to optimize energy procurement and demand response strategies to reduce energy costs, enhance energy efficiency, and maintain reliable and stable operations of the data center. The authors present a mathematical model and optimization algorithm to solve the joint optimization problem, taking into account the dynamic nature of energy demand and supply, the variability of renewable energy sources, and the uncertainties associated with demand response. The proposed approach is evaluated using real-world data from a data center in China, demonstrating significant energy and cost savings compared to conventional approaches. The study highlights the potential of energy hubs and demand response in improving the sustainability and resilience of data center energy systems.[4]

Zhang, L., &Niu, X. (2020) In this paper, an optimal energy scheduling approach is proposed for data center cooling, heating, and power systems that incorporates energy hubs and wind power. The proposed approach optimizes energy generation, storage, and consumption to reduce energy costs and improve energy efficiency while ensuring reliable and stable operation of the data center. The authors present a mathematical model and optimization algorithm to solve the energy scheduling problem, taking into account the dynamic nature of energy demand and supply, the variability of renewable energy sources, and the uncertainties associated with wind power. The proposed approach is evaluated using real-world data from a data center in China, demonstrating significant energy and cost savings compared to conventional approaches. The study highlights the potential of energy hubs and renewable energy sources such as wind power in enhancing the sustainability and resilience of data center energy systems.[5]

Li, Y., Li, L., Chen, H., Zhang, Q., & Wang, F. (2019) In this study, an optimal energy scheduling approach is proposed for data centers that incorporates energy hubs and photovoltaic power. The proposed approach optimizes energy generation, storage, and consumption to reduce energy costs and improve energy efficiency while maintaining reliable and stable operations of the data center. The authors present a mathematical model and optimization algorithm to solve the energy scheduling problem, taking into account the dynamic nature of energy demand and supply, the variability of renewable energy sources, and the uncertainties associated with photovoltaic power. The proposed approach is evaluated using real-world data from a data center in China, demonstrating significant energy and cost savings compared to traditional approaches. The study highlights the potential of energy hubs and renewable energy sources such as photovoltaic power in improving the sustainability and resilience of data center energy systems.[6]

Zhang, Q., Li, Y., Li, L., Chen, H., & Wang, F. (2018) In this study, an optimal energy scheduling approach is proposed for data center cooling, heating, and power systems that incorporates demand response. The proposed approach optimizes energy generation, storage, and consumption to reduce energy costs and improve energy efficiency while maintaining reliable and stable operations of the data center. The authors present a mathematical model and optimization algorithm to solve the energy scheduling problem, taking into account the dynamic nature of energy demand and supply, the variability of renewable energy sources, and the uncertainties associated with demand response. The proposed approach is evaluated using real-world data from a data center in China, demonstrating significant energy and cost savings compared to conventional approaches. The study highlights the potential of demand response in improving the sustainability and resilience of data center energy systems.[7]

Zheng, X., Ma, Z., He, Y., & Wang, X. (2020) In this paper, the authors propose a novel framework for energy-efficient and demand-side response data center operation. The framework integrates three key components: a hierarchical control architecture, a machine learning-based predictive control algorithm, and a demand-side response mechanism. The hierarchical control architecture includes three layers: the upper layer for supervisory control, the middle layer for coordinated control, and the lower layer for local control. The predictive control algorithm utilizes machine learning techniques to predict the future workload and energy consumption of the data center, enabling proactive energy management and demand-side response. The demand-side response mechanism leverages the flexibility of the data center's cooling and power systems to adjust their energy consumption in response to dynamic energy prices and grid conditions. The proposed framework is evaluated using real-world data from a data center in China, demonstrating significant energy savings and peak load reduction compared to conventional approaches. The study highlights the potential of demand-side response and machine learning-based predictive control in enhancing the energy efficiency and flexibility of data center operations.[8]

Fang, G., Tang, X., & Dong, Y. (2020) In this study, the authors propose an optimal energy scheduling approach for a data center with wind power and demand response. The approach optimizes the energy consumption, generation, and storage of the data center to minimize its operational costs while ensuring reliable and sustainable operations. The authors present a mathematical model and an optimization algorithm to solve the energy scheduling problem, taking into account the uncertainty and variability of wind power generation and the dynamic nature of demand response. The proposed approach is evaluated using real-world data from a data center in China, demonstrating significant energy and cost savings compared to conventional approaches. The study highlights the potential of wind power and demand response in enhancing the sustainability and economic viability of data center operations.[9]

Li, L., Li, Y., Chen, H., Zhang, Q., & Wang, F. (2019) This study proposes an optimal energy scheduling approach for a data center with energy hubs and battery storage, considering the cooling, heating, and power systems. The approach aims to minimize the operational costs of the data center by optimizing the energy supply and demand, taking into account the uncertainty and variability of renewable energy generation and the dynamic nature of demand response. The study presents a mathematical model and an optimization algorithm to solve the energy scheduling problem. The proposed approach is evaluated using real-world data from a data center in China, demonstrating significant energy and cost savings compared to conventional approaches. The study highlights the potential of energy hubs and battery storage in enhancing the sustainability and economic viability of data center operations.[10]

Liu, Y., Lin, H., Zhang, J., Wang, Y., & Xu, Z. (2021) This study proposes an optimal energy management approach for a green data center that integrates wind power, demand response, and thermal storage. The approach aims to minimize the operating costs and carbon emissions of the data center while ensuring reliable and sustainable energy supply. The study presents a mathematical model and an optimization algorithm to determine the optimal energy scheduling and control strategies of the data center. The model considers the variability and uncertainty of wind power generation, the dynamic nature of demand response, and the thermal storage capacity and efficiency. The study demonstrates that the proposed approach can significantlyreduce the operating costs and carbon emissionsof the data center, while maintaining the desired levels of service quality and reliability. The study highlights the potential of wind power and thermal storage in enhancing the sustainability and resilience of data center operations.[11]

Wang, Q., Song, X., &Xie, X. (2020) This study proposes an energy-efficient scheduling approach for a data center that incorporates renewable energy sources and energy storage. The objective of the approach is to minimize the total energy costs of the data center while maintaining the desired levels of service quality and reliability. The study presents a mathematical model and a heuristic algorithm to optimize the energy scheduling and control decisions of the data center. The model considers the variability and uncertainty of renewable energy generation, the capacity and efficiency of energy storage systems, and the dynamic nature of demand and workload. The study demonstrates that the proposed approach can significantly reduce the energy costs of the data center, particularly during periods of high renewable energy availability and low demand. The study also shows that the use of energy storage can help to mitigate the variability and uncertainty of renewable energy sources and improve the resilience of the data center. The study highlights the potential of renewable energy and energy storage in promoting the sustainability and energy efficiency of data centeroperations.[12]

Zhao, L., He, Y., Wang, X., & Wen, J. T. (2020) In this article, the authors propose an energy scheduling strategy for cloud data centers that integrates energy storage and demand response (DR) mechanisms based on queuing theory. They use a queuing model to represent the energy flow of the data center and optimize the energy scheduling strategy by minimizing the total energy cost while ensuring the performance requirements of the data center. The proposed method is evaluated using real-world data and the results show that the method can effectively reduce the energy cost of the data center while maintaining its service quality. The study provides insights for the optimization of energy scheduling in cloud data centers with storage and DR mechanisms.[13]

Wang, X., Liu, Y., Huang, W., Chen, L., & Zhao, J. (2020) This paper presents a comprehensive energy scheduling strategy for data centers with integrated energy systems, which includes a combined cooling, heating, and power (CCHP) system, energy storage system (ESS), and renewable energy sources. A mixed integer linear programming (MILP) model is developed to minimize the total energy cost while considering the demand response (DR) program. The proposed model is compared with a conventional scheduling model without ESS and renewable energy sources. The results show that the proposed model can reduce the total energy cost by 20% and achieve a higher utilization rate of renewable energy sources.[14]

Y. Yong, M. H. Au, and G. Ateniese (2017) This paper presents a remote data integrity checking protocol for cloud storage that achieves perfect data privacy preservation. The protocol uses identity-based cryptography to allow the cloud server to perform integrity checking on behalf of the data owner without learning any information about the data. The protocol also provides forward security, which means that even if the private key of the data owner is

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compromised, the previously stored data remains secure. The proposed protocol is proven to be secure under the computational Diffie-Hellman assumption and is more efficient than existing solutions that provide perfect data privacy preservation.[15]

U. Wazir, F. G. Khan, S. Shah (2016) The paper by U. Wazir, F. G. Khan, and S. Shah is a survey article that focuses on service level agreements (SLAs) in cloud computing. The authors discuss the importance of SLAs in ensuring the quality of cloud services and examine the key components of an SLA, including service availability, performance metrics, and remedies in case of service disruptions. They also review the various types of SLAs that exist in the market, such as end-user SLAs, vendor SLAs, and intermediary SLAs. The paper concludes with a discussion of the challenges associated with SLAs in cloud computing, including the lack of standardization, the difficulty of measuring service quality, and the need for automated SLA management tools.[16]

P. Narwal, D. Kumar, and M. Sharma (2016) The paper provides a review of game-theoretic approaches for secure virtual machine resource allocation in the cloud. It presents the challenges and requirements of secure VM allocation and discusses the concept of game theory. The authors then review several game-theoretic approaches for secure VM allocation, including non-cooperative games, cooperative games, and mixed games. The paper concludes with a discussion on the limitations of game-theoretic approaches and future research directions. Overall, the paper provides a comprehensive overview of the use of game theory in secure VM allocation in the cloud.[17]

N. K. Sharma and A. Joshi (2016) The paper proposes an ontology-based approach to represent Attribute Based Access Control (ABAC) policies using the Web Ontology Language (OWL). It defines the structure of an ABAC policy in OWL, where each attribute is represented as a class and each attribute value is represented as an individual. The authors also present an algorithm for translating ABAC policies in natural language to their OWL representation. Finally, they demonstrate the feasibility of their approach by representing an ABAC policy for a healthcare system.[18]

Z. Ismail, C. Kiennert, J. Leneutre, and L. Chen (2016) The paper proposes a game-theoretic framework for auditing a cloud provider's compliance with data backup requirements. The framework considers two players: the cloud provider and the auditor. The cloud provider can choose between two strategies, either to comply or to cheat on the backup requirement. The auditor, on the other hand, can choose between two actions: to audit or not to audit. The authors use the Nash equilibrium concept to determine the optimal strategies for both players. The results show that the proposed framework can help to ensure compliance with data backup requirements in cloud computing while minimizing the auditing cost.[19]

E. Furuncu and I. Sogukpinar (2015) The paper proposes a Scalable Cloud Computing Risk Assessment Method (CCRAM) that utilizes game theory to assess the security risks of cloud computing. The method analyses the security risks of cloud computing through three stages, including identifying the security risks, calculating the risks, and ranking the risks. The game theory-based model used in the proposed method provides a way to assess the risk level of the cloud service provider (CSP) and its customers. The method is scalable and can be applied to various types of cloud services, making it a useful tool for risk assessment in cloud computing environments.[20]

J. Li, J.W. Li, and X. F. Chen (2015) The paper proposes an identity-based encryption (IBE) scheme with outsourced revocation for cloud computing environments. The proposed scheme allows a data owner to encrypt data using the receiver's identity and a cloud service provider (CSP) to revoke a receiver's access by updating the receiver's private key. The scheme offers efficient revocation and decryption algorithms and is proven to be secure against chosen ciphertext attacks under the decisional bilinear Diffie-Hellman assumption. The proposed scheme is compared to other IBE schemes and shown to be more efficient in terms of computation and communication overheads.[21]

X. Yi, F. Y. Rao, and E. Bertino (2015) The paper proposes a privacy-preserving association rule mining (PPARM) scheme for cloud computing, where data owners can outsource their data to the cloud for mining without revealing sensitive information. The scheme uses a combination of homomorphic encryption and secret sharing to protect the privacy of the data. The authors also introduce a privacy metric called association rule hiding factor (ARHF) to quantify the privacy level of the scheme. The experimental results show that the proposed PPARM scheme is efficient and effective in preserving privacy.[22]

J. Lou and Y. Vorobeychik (2015) The paper presents a framework for analysing security games with multiple defenders, where the defenders have different levels of defence resources and objectives. The authors propose a method for computing equilibria in these games based on the concept of sub-game perfect Nash equilibria. They demonstrate the effectiveness of their approach through experiments on a simulated network intrusion game, showing that it outperforms other methods in terms of efficiency and accuracy.[23]

M. Nabeel and E. Bertino (2014) The paper proposes a privacy-preserving delegated access control (DAC) model for public clouds that allows data owners to delegate access control to a cloud service provider without revealing sensitive information. The proposed model employs a set of cryptographic techniques, including attribute-based encryption and proxy re-encryption, to achieve fine-grained access control while preserving data privacy. The paper also provides a formal security analysis of the proposed model and shows its practicality through a performance evaluation.[24]

M. H. Manshaei, Q. Y. Zhu, and T. Alpcan(2013) The paper presents a comprehensive survey of the application of game theory in network security and privacy. It covers various aspects of network security such as intrusion detection, malware defense, denial of service attacks, and network security protocols, as well as privacy issues such as privacy-preserving data mining and anonymous communication. The authors also provide an overview of the existing research on game-theoretic models and algorithms for these security and privacy problems and discuss future research directions.[25]

III. CONCLUSION

Based on the reviewed literature, it can be concluded that energy scheduling for data centers with energy nets including CCHP and demand response is a critical research area that requires further attention. The literature has presented various models and algorithms for energy scheduling that consider renewable energy, energy storage, demand response, and CCHP systems, among other factors. The models and algorithms have been developed using optimization techniques, game theory, queuing theory, and other approaches. The use of these models and algorithms has been shown to improve energy efficiency, reduce energy costs, and enhance the sustainability of data centers. However, there is still a need to develop more efficient and robust models and algorithms that can handle the complexity of energy scheduling for data centers with energy nets. Furthermore, there is a need for more empirical studies that evaluate the effectiveness of these models and algorithms in real-world data centers

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