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Day-Ahead Power Pricing Approach for Regional Consolidated Power Systems Including Power Cascade Utilization

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Abstract

The conventional energy system (ES) is characterized by excessive energy usage and elevated emissions. The Regional Consolidated Power Systems (RCPS) can meet diverse energy needs and attain clean, effective energy use via the connectivity of several ESs and variable energy transformation. The link between demand and supply for RCPS is intricate. RCPS struggles to optimize economic and effective operations without a rational energy supply framework. The multi-energy trade and service mechanisms remain ambiguous. The advancement of RCPS presents difficulties and opportunities within the energy industry. This research proposes a day-ahead energy trading approach for RCPS that incorporates Energy Cascade (EC) usage to resolve the promotion concerns associated with RCPS. The system categorizes the energy grades (EG) of manufacturing, transformation, and storage equipment while delineating the EG requirements of various energy demands. The energy-cascading efficiency trading system is simulated using empirical data. The simulation findings indicate that the trading plan is viable, and using the EC utilization method can enhance the effectiveness of electrical power utilization RCPS.

Keywords: Power Systems, Cascade Utilization, Prediction, Power Pricing.

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Introduction

Energy is essential for the survival of human communities and serves as a crucial material foundation (Miao et al., 2020). The conventional energy supply system's energy efficiency (EE) is suboptimal, leading to elevated energy consumption and significant emissions (Yu et al., 2021). EE usage is a vital technology in sustainable energy growth, and the Integrative Energy System (ES) (IES) has emerged as a compelling technology (Zhang et al., 2019). IES can optimize energy utilization through flexible conversion methods by integrating various electrical systems. The Regional Consolidated Power Systems (RCPS) (Vaiman et al., 2011), situated on the electricity user side, is a significant variant of IES. The RCPS encompasses several kilometers of land to satisfy the diverse energy requirements of consumers in the "regions." It can integrate several ESs, dynamically convert electrical, thermal, and cooling energy to deliver EE and assimilate dispersed renewable energy.

Shortcomings persist in studying RCPS optimal scheduling techniques and multi-energy trading (ET) studies (Aquila et al., 2023). The absence of a rational energy supply framework hinders RCPS from achieving optimal economic and efficient functioning. Several ambiguous and unclear assertions remain regarding the duties of all parties in the multi-method.

This work provides a day-ahead technique for renewable integrated ESs, considering energy cascade (EC) usage, as summarized from prior research. The utilization supply framework for RCPS is established to enhance the effectiveness of multi-energy devices. This study presents a more extensive multi-energy day-ahead trading approach (ME-DA-TA).

Background

The non-cooperative game concept and the Stackelberg game have garnered significant interest in facilitating energy exchange while maintaining the autonomy and privacy of each trading actor. The research developed an electricity and carbon market system utilizing the dual-Stackelberg game theory. It provided electricity trading techniques for demand and supply aspects amid the uncertainty of complete energy needs (Mundotiya et al., 2022; Singh & Singal, 2017). The research provided a model for sharing power and Demand Reaction (DR) among Photovoltaic (PV) customers within a market context. It developed a dynamic internal pricing model depending on PV energy's Supply-Demand Ratio (SDR). The research presented a multi-follower, two-tier optimization strategy to address the energy transaction challenges in microgrids (MG) (Liu et al., 2023) using Combined Heat and Power (CHP) systems, considering both day-ahead (DA) and real-time energy dispatching. The research introduced a hierarchical dispatch mechanism synchronizing ET among autonomous market participants and these systems. The study devised an iterative pricing system for Peer-To-Peer (P2P) energy transactions within community MG utilizing non-cooperative activities, evolutionary activities, and Stackelberg plays. The study established a dual-tier framework for makers of prices (virtual power stations) to engage in day-ahead, aiming to optimize earnings and mitigate the associated hazards. The study employed Stackelberg's theory of games to develop an energy optimization framework for multi-energy parks, incorporating a bidirectional power trade among leaders and followers. The research can identify the Nash equilibrium solution among individuals; they cannot concurrently integrate personal and social advantages, resulting in outcomes that are typically non-Pareto and non-socially optimal.

DR programs should be integrated into users' EE scheduling considerations to enhance the temporal coherence of both demand and supply approaches. In the IES, DR can be expanded to encompass various types of warmth and electricity, which is referred to as Integrated Demand Response (IDR) (Mosbah & El-Hawary, 2016) due to the consumer's diverse energy requirements and the inherent effect of substitution among various types of energy. The research examined multi-stakeholder behavior inside distributed power systems and assessed the impact of the carbon price and demand response on multi-stakeholder energy dispatching. The study offered a day-ahead price and management framework for integrated ESs, considering multi-energy DR. The research project introduced an integrated multi-energy optimization approach to Energy Hubs (EH) from the supplier side perspective and formulated an optimization efficiency with multiple objectives for EH. Using IDR, the study presented a day-ahead and intra-day planning technique for MG and built a two-stage solid optimization framework. IDR will be a crucial element in achieving synergistic improvement of the demand and supply aspects of the IES.

Proposed Day-Ahead Power Pricing Approach

3.1 EC Utilization Concept

The concept of EC utilization is proposed for the efficient use of heat. Heat is categorized into several classes in this energy application and employed for distinct purposes to optimize energy use. The method of heat classification is as follows. The rating of heat is the primary distinguishing criterion for assessing heat quality. The boiling point of heat reflects the ratio of accessible energy to unit heat energy, which is the critical factor for classifying the thermal energy grade (EG). Thermal energy is typically categorized into three classifications: high-grade warmth, medium-grade heat, and low-grade warmth. The boiling point range of high-grade heat spans from 500 degrees Fahrenheit to the hypothetical combustion point. The average temperature range for middle-grade warmth is from 190 degrees Celsius to 500 degrees Celsius. The boiling point range of low-grade heat extends from the outdoors to a maximum of 180 degrees Celsius.

3.2 RCPS Electric Cascade Structure of Energy Source

Two essential aspects must be considered when applying the EC usage theory to RCPS dispatching. The grades for different device signals should be categorized. The thermal grade requirements of various loads must be elucidated. In RCPS, the primary energy generation devices consist of Gas Turbines (GT) and their boilers and PV. The energy-converting devices comprise a heat pump, an electric cooler, and an absorbent chiller. The energy storage mechanisms comprise an energy source and a heat chamber. The gas turbine generators utilize natural gas from the regional gas system to generate high-grade heat for electricity generation. The gas turbine boilers collect leftover medium-grade heat to produce heated water (medium-grade heat) and flue gas (low-grade warmth). Medium-grade heated steaming can serve as an energy source for absorption chillers or be delivered to steam loading and Auxiliary Cooling Loads (ACLs). The low-grade flue gas the heating system generates can be utilized for thermal loads (hot steam) or chilling following conversions. Hot low-grade steam can be reclaimed from steam loads.

3.3 RCPS day-Ahead Power Trading Strategies

Following the elucidation of RCPS EC consumption, the functions of transaction entities and their interrelations within a trading plan are examined. The ME-DA-TA approach involves transaction entities for energy suppliers (ESs), IES providers (IESPs), and energy users (EUs). ESs are substantial energy corporations. They manage the MG or natural gas systems. Energy suppliers supply electric energy and natural gas to networked energy service companies at wholesale rates. IESPs get profit from three primary sources. IESP acquires power and petroleum products from EUs at wholesale rates. IESP utilizes its proprietary energy-shared production, transformation, and storage systems to produce electricity, thermal energy, and cooling energy, depending on the acquired energy, while establishing retail rates. IESP engages in physical sales with EUs to satisfy their energy requirements and generate profits.

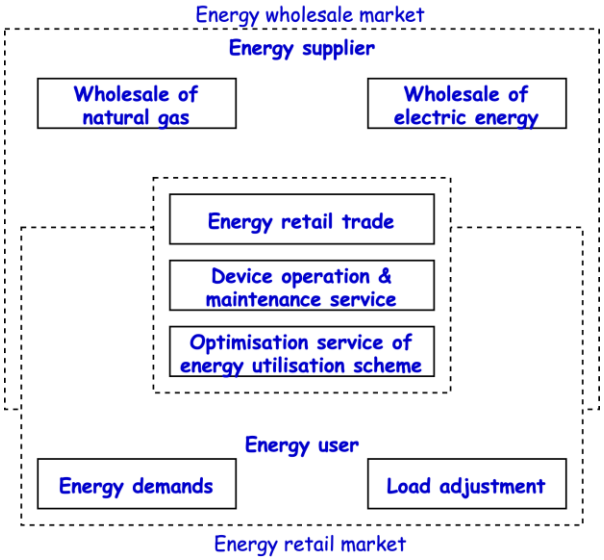


Fig. 1: Day-Ahead Model

IESP offers device upkeep and operation assistance to end users in need, generating revenue from service fees.

Optimization services for energy consumption schemes: utilizing big data analytics technologies, IES develops economically viable, effective, and pleasant energy utilization strategies for end users. EUs contract with an IESP for a specified duration. During this time, EUs engage in energy exchanges with the IESP and acquire various services to fulfill their energy usage requirements for economic efficiency, reliability, and pleasure. The RCPS day-ahead trading of the electricity method is illustrated in Fig. 1.

Results

The outcomes of the day-ahead price of energy optimization are illustrated in Figure 6. The average retail cost of electricity established by IESP indicates that its highest value is inferior to that of the highest electric power wholesale cost. Between 7:00 and 10:00, user-side electrical demand for energy is minimal, prompting the IESP to provide reduced retail pricing to incentivize consumers to consume electricity. During the subsequent timeframe, consumer-side electric consumption escalated, prompting the IESP to establish elevated electric power retail prices to generate a consistent profit. In short, when the wholesale cost of electricity increases, IESP profits by establishing the retail cost of electric energy among the peak and baseline wholesale prices.

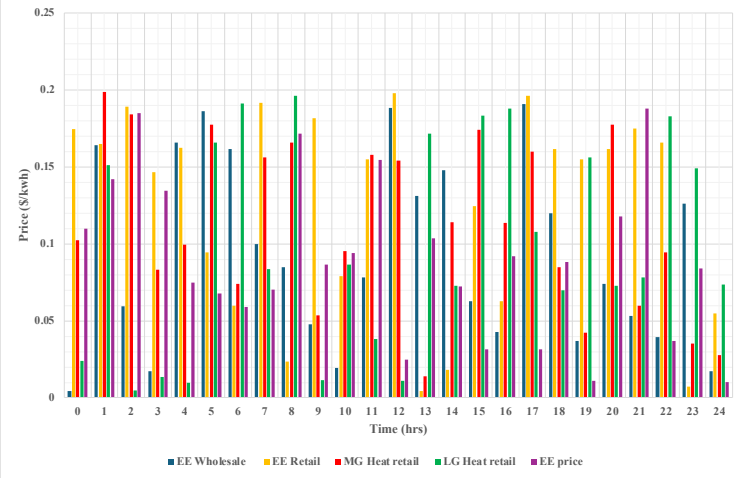


Fig. 2: Daily Load Price Analysis

During the valley wholesale pricing phase, the IESP establishes a reduced price. During certain intervals when end users are inactive in acquiring electricity, the Independent Electricity Supply Provider establishes reduced retail prices for electricity to encourage use. Intermediate-grade thermal energy is mainly provided for manufacturing steam requirements. These loads exhibit stability. The retail price of mid-grade thermal energy is generally steady. Between 0:00 and 4:00, the minimum need for middle-grade thermal power on the user end is prompting the lESP to establish reduced retail pricing to incentivize EUs to utilize thermal power. As the need for middle-grade thermal energy escalates, the retail price incrementally increases and attains a stable equilibrium. Low-grade thermal power is mainly used for hot water demands and air conditioning loads, and its retail cost remains consistent. Between 20:00 and 24:00, as well as from 00:00 to 05:00, the need for low-grade thermal energy on the part of users is minimal, and the IESP establishes a reduced retail cost.

Conclusion

The results of energy devices are classed according to EGs. The EG requirements of user-side consumption are categorized—the day-ahead structure, RCPS, is constructed based on grade equivalents and cascade usage principles. The bi-level optimization framework is converted into a single-objective optimization framework utilizing circumstances and the large M technique. The approach delineated in this study can furnish reliable information across diverse applications. The IESPs can employ the suggested approach to establish energy retail pricing and ascertain the ideal trading plan in both the power wholesale and sales markets. The EU can utilize the presented technique to build an energy usage plan. The governmental organization can utilize energy transaction data and modify essential market variables, such as wholesale energy pricing, to ensure a stable market. This study proposes a bi-level trading approach, driven by IESP, utilizing the Stackelberg framework game. A pricing approach

and a power supply architecture are presented using the EC principle to enhance the EE in RCPS. The transaction technique fails to account for developing market elements, such as sharing economics and peer-to-peer trade. Subsequent studies will improve the trading approach.

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