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CVaR-Based Optimal Scheduling of an Integrated Energy System with Battery Storage, Hydrogen Storage, and Demand Response

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Abstract: High renewable penetration improves the low-carbon performance of integrated energy systems, but it also increases scheduling uncertainty and renewable curtailment risk. This paper proposes a CVaR-based optimal scheduling model for an electric-heat-hydrogen integrated energy system with battery energy storage, hydrogen storage, and demand response. The proposed model minimizes a weighted objective that combines expected operating cost and tail-risk cost, while considering electricity purchase and sale, gas consumption, carbon emissions, battery degradation, hydrogen conversion, demand response compensation, and renewable curtailment penalty. Wind power, photovoltaic generation, and electric load uncertainty are represented by multiple scenarios, and the same scenario set is used for all comparative cases to ensure fairness. Five operation schemes are studied, including no storage, battery energy storage only, hydrogen storage only, battery-hydrogen storage, and the proposed battery-hydrogen-demand response scheme. The numerical results show that the proposed scheme achieves the lowest weighted objective, expected cost, and CVaR cost. Compared with the no-storage case, the proposed scheme reduces the weighted objective from 12337.22 to 9677.39, increases renewable utilization from 92.3% to 99.8%, and reduces expected carbon emissions from 4771.88 to 2994.13. These results indicate that coordinated scheduling of battery storage, hydrogen storage, and demand response can improve economic performance, reduce operational risk, and enhance renewable energy accommodation in high-renewable integrated energy systems.

Keywords: Integrated energy system; Optimal scheduling; CVaR; Battery energy storage; Hydrogen storage; Demand response; Renewable curtailment

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1. Introduction

The rapid growth of renewable energy has changed the operation pattern of modern energy systems. Wind power and photovoltaic generation can reduce fossil fuel consumption and carbon emissions, but their output is strongly affected by weather conditions. When renewable generation fluctuates, the system operator must balance electricity, heat, and storage resources under greater uncertainty. Integrated energy systems provide an effective framework for this problem because they coordinate multiple energy carriers, such as electricity, heat, gas, and hydrogen. Through energy conversion devices and flexible resources, an integrated energy system can improve renewable energy utilization and reduce dependence on conventional fossil-based supply.

Battery energy storage, hydrogen storage, and demand response have different operational characteristics so that they can provide complementary flexibility. Battery energy storage has high conversion efficiency and fast response speed, which makes it suitable for short-term power balancing and peak shaving. Hydrogen storage has lower round-trip efficiency, but it can absorb surplus renewable electricity through electrolysis and release energy later through fuel cells. It is therefore more suitable for longer-duration renewable energy accommodation. Demand response adjusts flexible load on the demand side and can reduce peak-hour pressure without installing additional generation capacity. If these resources are scheduled independently, their flexibility may not be fully used. A coordinated scheduling strategy is needed to determine when each resource should operate and how it should contribute to cost reduction, renewable utilization, and emission mitigation.

The uncertainty of renewable generation and load demand makes deterministic scheduling insufficient for high-renewable integrated energy systems. A dispatch scheme that performs well under forecasted conditions may lead to high operating costs when wind power, photovoltaic generation, or load demand deviates from the expected profile. Scenario-based stochastic optimization can describe different operating conditions, but the expected-cost criterion may underestimate low-probability adverse scenarios. Conditional value-at-risk provides a practical way to measure the average cost in the high-cost tail of the scenario distribution. By introducing CVaR into the scheduling model, the operator can reduce the exposure to extreme operating costs while still considering the average economic performance of the system.

Existing studies have investigated long-term planning and key technologies for high-renewable power systems, green-electricity direct connection and source-grid-load-storage coordinated scheduling, electricity-hydrogen-carbon ecosystems and power-hydrogen-ammonia coupling systems, and hydrogen-electric-thermal or electric-hydrogen coordinated dispatch strategies [1–12]. In addition, energy storage configuration and flexible load integration have been studied for regional integrated energy systems and distribution networks, while low-carbon scheduling considering flexible-load uncertainty has also been discussed [13–15]. However, relatively limited attention has been paid to the joint coordination of battery storage, hydrogen storage, and demand response under a CVaR-based tail-risk framework for high-renewable electric-heat-hydrogen integrated energy systems.

This paper develops a CVaR-based optimal scheduling model for an electric-heat-hydrogen integrated energy system. The main contributions are threefold. First, battery energy storage, hydrogen storage, and demand response are jointly coordinated in a unified scheduling framework, which allows short-term and long-duration flexibility to be used in a complementary manner. Second, renewable curtailment is explicitly modeled and penalized in the objective function, so the model can evaluate renewable accommodation more directly than approaches that only infer curtailment from power export. Third, a weighted objective combining expected operating cost and CVaR cost is adopted to balance average economic performance and tail-risk control under renewable generation and load uncertainty.

2. System description

The studied system is an electric-heat-hydrogen integrated energy system with renewable generation, conventional energy supply, energy conversion devices, storage units, grid interaction, and flexible demand. The electric side includes wind power, photovoltaic generation, electric load, grid electricity purchase and sale, gas turbine generation, battery energy storage, electrolyzer consumption, fuel cell generation, heat pump consumption, and demand response. The heat side includes heat load, gas turbine heat recovery, gas boiler heat production, heat pump heat output, and fuel cell waste heat recovery. The hydrogen side consists of an electrolyzer, a hydrogen storage tank, and a fuel cell. The electrolyzer converts surplus electricity into hydrogen, while the fuel cell converts stored hydrogen back into electricity and also provides usable heat.

Battery energy storage and hydrogen storage are assigned different operational roles in the system. Battery energy storage has high charging and discharging efficiency, so it is mainly used to smooth short-term renewable fluctuations and reduce peak electricity purchase. Hydrogen storage has a lower electric round-trip efficiency, but it can store a larger amount of surplus renewable energy over a longer period. This makes it useful when photovoltaic generation is high, and the battery capacity is insufficient to absorb all renewable output. Demand response is modeled as an interruptible electric load. It reduces the net electric demand during selected periods and provides additional flexibility when storage resources alone cannot fully relieve peak-hour pressure.

3. Mathematical model

A two-stage scenario-based scheduling model is formulated for the integrated energy system. All scenarios share the first-stage decisions and represent the scheduled outputs of the main conversion devices before the realization of renewable generation and load uncertainty. The second-stage decisions are scenario-dependent and describe corrective operation after the uncertain variables are observed. These decisions include grid exchange, battery charging and discharging, hydrogen production and utilization, demand response, and renewable curtailment. The scheduling horizon is divided into 24 hourly periods. The objective is to minimize a weighted sum of the expected operating cost and the CVaR cost, while satisfying electricity balance, heat balance, storage dynamics, device limits, and risk-related constraints.

3.1. Objective function

The objective function consists of the expected operating cost and the CVaR cost. The expected operating cost represents the average economic performance of the system over all scenarios. The CVaR cost measures the expected loss in the high-cost tail of the scenario distribution. By combining these two terms, the proposed model can reduce the average operating cost while controlling the risk caused by renewable generation and load uncertainty. Let C_s denote the total operating cost in scenario s, and let S denote the number of scenarios. The weighted objective function is formulated as follows:

$$minF = (1-\beta)\frac{1}{S}\sum_{s=1}^{S}C_s + \beta\left[\eta + \frac{1}{(1-\alpha)S}\sum_{s=1}^{S}z_s\right]$$

where β is the risk weight, α is the confidence level of CVaR, η is the value-at-risk auxiliary variable, and z_s is the non-negative excess cost variable in scenario? s . The CVaR auxiliary constraints are expressed as:

$$z_s \geq C_s - \eta, \quad \forall s$$

$$z_s \geq 0, \quad \forall s$$

The scenario operating cost C_s includes electricity purchasing cost, electricity selling revenue, gas consumption cost, operation and maintenance cost, carbon emission cost, battery degradation cost, hydrogen conversion cost, demand response compensation, and renewable curtailment penalty. It can be written as:

$$C_s = C_s^{\mathrm{grid}} + C_s^{\mathrm{gas}} + C_s^{\mathrm{om}} + C_s^{\mathrm{carbon}} + C_s^{\mathrm{bat}} + C_s^{\mathrm{h2}} + C_s^{\mathrm{dr}} + C_s^{\mathrm{curt}}$$

In this formulation, the expected-cost term encourages economical operation under normal scenarios, while the CVaR term limits the average cost of adverse scenarios. Therefore, the model is not only cost-oriented but also risk-aware. This is important for high-renewable integrated energy systems, because renewable output and load demand may deviate from their forecasted values and cause expensive corrective operation.

3.2. Energy balance constraints

The integrated energy system must satisfy electricity and heat balance in each time period and under each scenario. The electricity balance links renewable generation, grid interaction, gas turbine output, battery operation, hydrogen conversion, heat pump consumption, and demand response. For time period t and scenario s , the electric power balance is expressed as:

$$P_{t,s}^{wt} + P_{t,s}^{pv} - P_{t,s}^{curt,wt} - P_{t,s}^{curt,pv} + P_{t,s}^{gt} + P_{t,s}^{fc} + P_{t,s}^{bat,dis} + P_{t,s}^{grid,buy} = L_{t,s}^{e} - P_{t,s}^{dr} + P_{t,s}^{hp} + P_{t,s}^{el} + P_{t,s}^{bat,ch} + P_{t,s}^{grid,sell}$$

where $P_{t,s}^{wt}$ and $P_{t,s}^{pv}$ are the available wind and photovoltaic power, respectively. $P_{t,s}^{curt,wt}$ and $P_{t,s}^{curt,pv}$ represent curtailed wind and photovoltaic power. $P_{t,s'}^{gt} P_{t,s'}^{fc}$ and $P_{t,s^{bat,dis}}^{bat,dis}$ are the electric outputs of the gas turbine, fuel cell, and battery. $P_{t,s}^{grid,buy}$ and $P_{t,s}^{grid,sell}$ are the purchased and sold electricity from the main grid. On the demand side, $L_{t,s}^{e}$ is the electric load, $P_{t,s}^{dr}$ is the interrupted demand response load, $P_{t,s}^{hp}$ is the electric consumption of the heat pump, $P_{t,s}^{el}$ is the electric consumption of the electrolyzer, and $P_{t,s}^{bat,ch}$ is the battery charging power.

The heat balance ensures that the heat load is supplied by heat recovery and heat-producing devices. It is given by:

$$H_{t,s}^{gt} + H_{t,s}^{gb} + H_{t,s}^{hp} + H_{t,s}^{fc} = L_{t,s}^{h}$$

where $H_{t,s}^{gt}$ is the recovered heat from the gas turbine, $H_{t,s}^{gb}$ is the heat output of the gas boiler, $H_{t,s}^{hp}$ is the heat output of the heat pump, $H_{t,s}^{fc}$ is the recovered heat from the fuel cell, and $L_{t,s}^{h}$ is the heat load. The heat pump output is related to its electric consumption by:

$$H_{t,s}^{hp} = COP^{hp} P_{t,s}^{hp}$$

The renewable curtailment variables are constrained by the available renewable generation:

$$0 \leq P_{t,s}^{curt,wt} \leq P_{t,s}^{wt}, \quad \forall t,s$$

$$0 \leq P_{t,s}^{curt,pv} \leq P_{t,s}^{pv}, \quad \forall t,s$$

These balance constraints ensure that electricity and heat demands are met at all times. They also allow surplus renewable energy to be absorbed by battery charging, hydrogen production, grid export, or demand-side adjustment. If these flexibility resources are insufficient, renewable curtailment occurs and is penalized in the objective function.

3.3. Storage and hydrogen constraints

Battery energy storage is used to transfer electric energy across time periods. Its state of charge changes according to the charging and discharging power. For time period t and scenario s, the battery energy dynamics are formulated as:

$$E_{t,s}^{\mathrm{bat}} = E_{t-1,s}^{\mathrm{bat}} + \eta^{\mathrm{ch}} P_{t,s}^{\mathrm{bat,ch}} \Delta t - \frac{P_{t,s}^{\mathrm{bat,dis}} \Delta t}{\eta^{\mathrm{dis}}}$$

where $E_{t,s}^{\mathrm{bat}}$ is the stored energy of the battery, $P_{t,s}^{\mathrm{bat,ch}}$ and $P_{t,s}^{\mathrm{bat,dis}}$ are the charging and discharging power, η^{ch} and η^{dis} are the charging and discharging efficiencies, and Δt is the scheduling time interval. The battery power and energy limits are given by:

$$0 \le P_{t,s}^{\mathrm{bat,ch}} \le u_{t,s}^{\mathrm{bat,ch}} P_{\mathrm{max}}^{\mathrm{bat}}$$

$$0 \le P_{t,s}^{\mathrm{bat,dis}} \le u_{t,s}^{\mathrm{bat,dis}} P_{\mathrm{max}}^{\mathrm{bat}}$$

$$E_{\mathrm{min}}^{\mathrm{bat}} \le E_{t,s}^{\mathrm{bat}} \le E_{\mathrm{max}}^{\mathrm{bat}}$$

To avoid simultaneous charging and discharging, the following binary constraint is imposed:

$$u_{t,s}^{\mathrm{bat,ch}} + u_{t,s}^{\mathrm{bat,dis}} \le 1$$

The initial and terminal battery energy levels are constrained to be equal:

$$E_{0,s}^{\mathrm{bat}} = E_{\mathrm{ini}}^{\mathrm{bat}}$$

$$E_{T,s}^{\mathrm{bat}} = E_{\mathrm{ini}}^{\mathrm{bat}}$$

Hydrogen storage is coupled with the electrolyzer and the fuel cell. The electrolyzer consumes electricity to produce hydrogen, while the fuel cell consumes hydrogen to generate electricity and heat. The hydrogen storage dynamics are described as:

$$H_{t,s}^{\mathrm{h2}} = H_{t-1,s}^{\mathrm{h2}} + \eta^{\mathrm{el}} P_{t,s}^{\mathrm{el}} \Delta t - \frac{P_{t,s}^{\mathrm{fc}} \Delta t}{\eta^{\mathrm{fc}}}$$

where $H_{t,s}^{h2}$ is the hydrogen storage level, $P_{t,s}^{el}$ is the electrolyzer power, $P_{t,s}^{fc}$ is the electric output of the fuel cell, η^{el} is the hydrogen production efficiency of the electrolyzer, and η^{fc} is the electric conversion efficiency of the fuel cell. The operation limits of the electrolyzer, fuel cell, and hydrogen storage tank are expressed as:

$$0 \le P_{t,s}^{el} \le u_{t,s}^{el} P_{max}^{el}$$

$$0 \le P_{t,s}^{fc} \le u_{t,s}^{fc} P_{max}^{fc}$$

$$H_{min}^{h2} \le H_{t,s}^{h2} \le H_{max}^{h2}$$

The electrolyzer and fuel cell are not allowed to operate at the same time, which is enforced by:

$$u_{t,s}^{el} + u_{t,s}^{fc} \le 1$$

The initial and terminal hydrogen storage levels are also required to be equal:

$$H_{0,s}^{h2} = H_{ini}^{h2}$$

$$H_{T,s}^{h2} = H_{ini}^{h2}$$

These constraints describe the intertemporal behavior of the two storage resources. Battery energy storage mainly provides short-term electric flexibility with high efficiency, while hydrogen storage provides longer-duration renewable energy absorption. The terminal constraints prevent the model from obtaining an artificial cost reduction by simply depleting stored energy at the end of the scheduling horizon.

3.4. Demand response and operational constraints

Demand response is modeled as an interruptible electric load. It provides load-side flexibility during high-cost or high-risk periods. For each time period and scenario, the interrupted load is limited by a fixed proportion of the electric demand:

$$0 \le P_{t,s}^{dr} \le \gamma^{dr} L_{t,s}^{e}, \quad \forall t, s$$

where P_t, s^{dr} is the interrupted demand response load, γ^{dr} is the maximum interruption ratio, and L_t, s^{e} is the electric load. To avoid unrealistic load reduction over the whole scheduling horizon, the total interrupted energy is further constrained by:

$$\sum_{t=1}^{T} P_{t,s}^{dr} \Delta t \le \Gamma^{dr} \sum_{t=1}^{T} L_{t,s}^{e} \Delta t, \quad \forall s$$

where Γ^{dr} is the maximum daily interruption ratio. This constraint reflects the limited availability of flexible demand. In this study, demand response should be interpreted as interruptible load rather than shiftable load, because the reduced demand is not transferred to other periods.

The gas turbine and the heat pump are coupled with the heat balance through their conversion relationships. The recovered heat from the gas turbine is proportional to its electric output:

$$H_{t,s}^{gt} = a^{gt} P_{t,s}^{gt}, \quad \forall t, s$$

where a^{gt} is the heat-to-power ratio of the gas turbine. The heat pump output is determined by its coefficient of performance:

$$H_{t,s}^{hp} = COP^{hp} P_{t,s}^{hp}, \quad \forall t, s$$

The main grid interaction is also constrained. The system can purchase electricity from the grid or sell surplus electricity to the grid, but a binary variable prevents simultaneous buying and selling:

$$0 \le P_{t,s}^{grid,buy} \le u_{t,s}^{grid} P_{max}^{grid,buy}$$

$$0 \le P_{t,s}^{grid,sell} \le \left(1 - u_{t,s}^{grid}\right) P_{max}^{grid,sell}$$

where $u_{t,s}^{grid}$ is a binary grid operation variable. This treatment avoids artificial arbitrage between buying and selling electricity in the same period. The export capacity is set lower than the purchase capacity, which represents a practical limitation on renewable power delivery to the external grid.

The risk constraints are embedded in the CVaR formulation. For each scenario, the excess cost variable z_s measures the part of the scenario cost that exceeds the auxiliary threshold η. This structure penalizes high-cost scenarios and encourages the dispatch strategy to remain economical under renewable and load uncertainty. In the optimization results, the CVaR value is therefore used as a risk-oriented performance index in addition to the expected operating cost.

3.5. Solution procedure and case design

The proposed model is solved over a 24-hour scheduling horizon with an hourly time resolution. Wind power, photovoltaic power, and electric load are represented by a set of uncertainty scenarios. The same scenario set is used for all comparative cases, so the performance differences are caused by the configuration of flexible resources rather than by random scenario variation. Five cases are designed for comparison: a system without storage, a system with battery energy storage only, a system with hydrogen storage only, a system with both battery energy storage and hydrogen storage, and the proposed system with battery energy storage, hydrogen storage, and demand response. **Figure 1** presents the weighted objective, expected operating cost, CVaR cost, and computational time of the five cases.

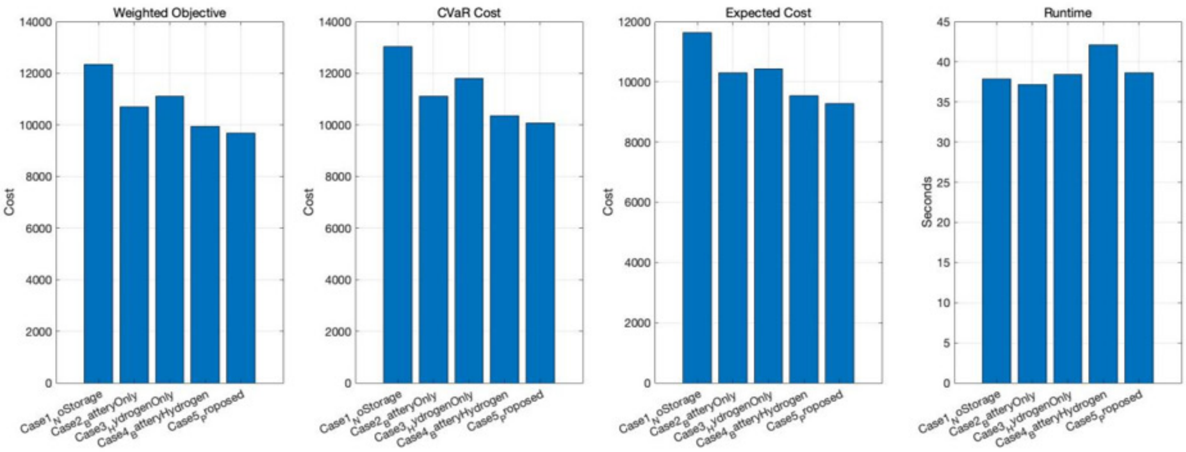

Figure 1. Cost and runtime.

4. Case study

A 24-hour case study is conducted to evaluate the proposed risk-aware optimal dispatch model for the electric-heat-hydrogen integrated energy system. The scheduling interval is one hour. Wind power, photovoltaic power, and electric load are treated as uncertain variables and represented by multiple scenarios. To ensure a fair comparison, the same scenario set is used for all cases. Five configurations are compared, including no storage, battery storage only, hydrogen storage only, battery-hydrogen storage, and the proposed battery-hydrogen-demand response scheme.

4.1. Economic and risk performance analysis

As shown in **Figure 1**, the proposed battery-hydrogen-demand response scheme achieves the lowest weighted objective, expected operating cost, and CVaR cost among the five cases, while maintaining an acceptable computational time. This indicates that the coordinated use of battery storage, hydrogen storage, and demand response improves both economic performance and tail-risk control under renewable generation and load uncertainty.

The results show that the proposed case achieves the best economic and risk performance. Compared with the no-storage case, the weighted objective decreases from 12337.22 to 9677.39, which corresponds to a reduction of 21.56%. The expected operating cost decreases by 20.15%, and the CVaR cost decreases by

22.82%. This indicates that the proposed scheduling strategy can reduce both average operating cost and tail-risk cost under renewable generation and load uncertainty. The battery-only case also performs well, since battery storage has high round-trip efficiency and can respond quickly to short-term renewable fluctuations. However, the hydrogen-only case has a higher weighted objective than the battery-only case, even though it improves renewable utilization. This result is reasonable because hydrogen conversion involves larger energy losses than battery storage. The battery-hydrogen case further reduces both expected cost and CVaR cost, showing that short-term battery flexibility and longer-duration hydrogen storage are complementary. After demand response is added, the proposed case obtains the lowest weighted objective. This improvement suggests that load-side flexibility can reduce high-cost peak-period operation and improve the risk-aware dispatch performance.

4.2. Renewable utilization and curtailment analysis

As shown in **Figure 2**, renewable utilization increases and curtailment decreases as flexible resources are gradually introduced. The proposed scheme achieves the highest renewable utilization and the lowest curtailment rate, and it also reduces expected carbon emissions compared with the no-storage case. These results demonstrate that the coordination of battery storage, hydrogen storage, and demand response can enhance renewable energy accommodation and improve the low-carbon performance of the integrated energy system.

The no-storage case exhibits the highest renewable curtailment because excess wind and photovoltaic generation cannot be shifted to other periods. Introducing battery storage significantly improves renewable utilization by absorbing short-term surplus power and releasing it during high-demand periods. The hydrogen-only case also reduces curtailment by converting excess renewable electricity into hydrogen, demonstrating its advantage in long-duration energy storage. When battery and hydrogen storage are jointly deployed, their complementary operating characteristics enable the system to accommodate a larger proportion of renewable generation. The proposed case achieves the highest renewable utilization and the lowest curtailment after demand response is incorporated. This result indicates that coordinating short-term battery storage, long-duration hydrogen storage, and flexible demand can effectively mitigate renewable power fluctuations and enhance the system's overall renewable energy accommodation capability.

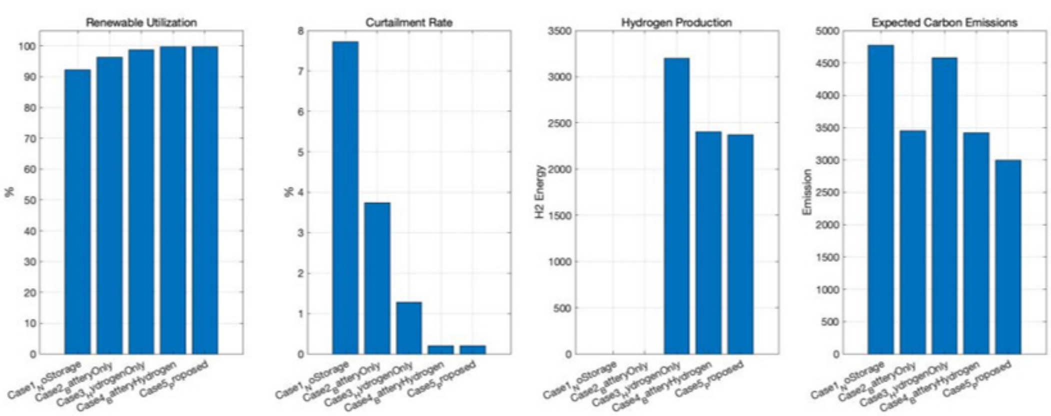

Figure 2. Energy and emission metrics.

4.3. Energy storage and demand response operation analysis

As shown in **Figure 3**, the best-case dispatch profile illustrates the complementary operation of battery storage, hydrogen storage, and demand response. The battery charges during renewable-rich or low-price periods and discharges during peak-load periods, while hydrogen production absorbs sustained renewable surplus and the fuel cell supports the system when a power shortage occurs. Demand response further reduces peak demand, thereby lowering grid dependence and improving operational flexibility.

The battery mainly charges during periods of surplus renewable generation or low electricity prices and discharges during peak-load or high-price periods. This operating pattern confirms its role in managing short-term power fluctuations and peak–valley differences. In contrast, the hydrogen storage system absorbs sustained renewable surplus through the electrolyzer and supplies energy through the fuel cell when power shortages occur, thereby providing longer-duration energy shifting. Demand response further adjusts the load profile by transferring flexible demand from peak periods to periods with abundant renewable generation. The coordinated operation of these resources reduces peak grid dependence, improves renewable energy consumption, and lowers exposure to high-cost scenarios. Therefore, battery storage, hydrogen storage, and demand response perform complementary functions in the proposed risk-aware scheduling framework. (See **Figure 3**)

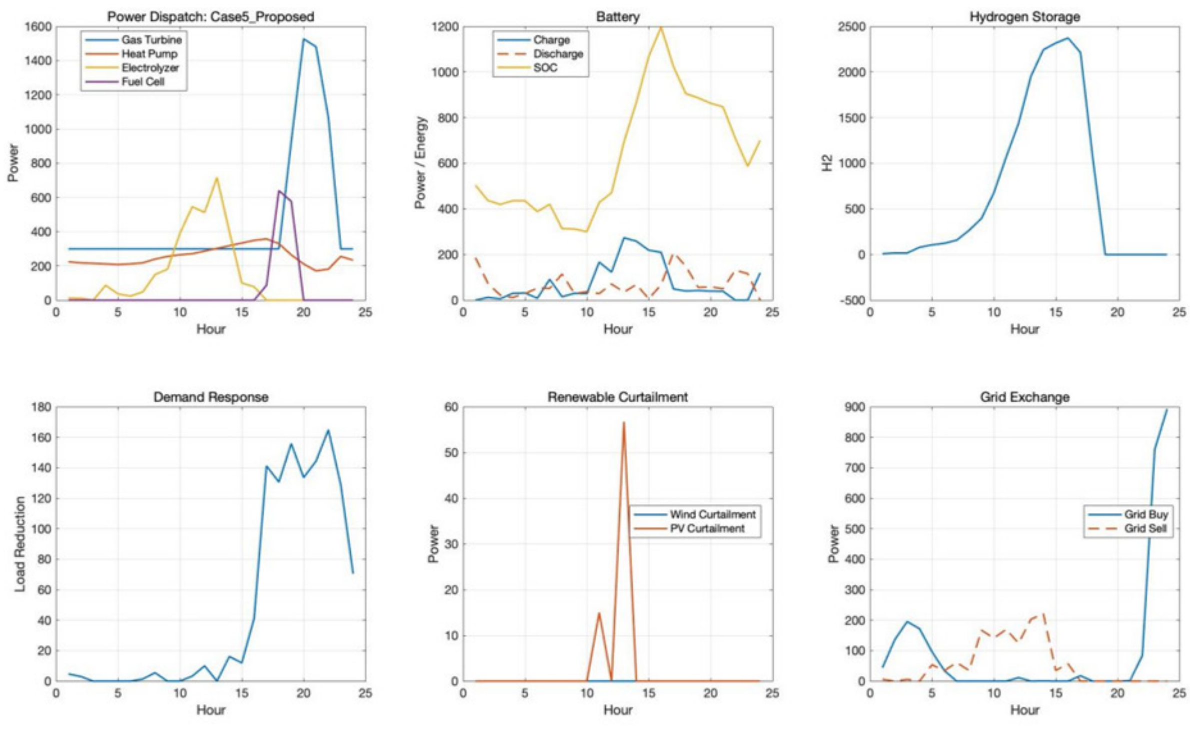

Figure 3. Best case dispatch.

4.4. Chapter summary

This chapter evaluates the proposed two-stage CVaR-based scheduling strategy under five system configurations. The results demonstrate that coordinating battery storage, hydrogen storage, and demand response achieves the lowest weighted objective, expected operating cost, and CVaR cost. The proposed case also improves renewable energy utilization and reduces curtailment through the complementary operation of short-term battery storage and long-duration hydrogen storage. Demand response further enhances scheduling flexibility by shifting loads away from peak and high-cost periods. Overall, the proposed strategy improves the economic efficiency, renewable energy accommodation capability, and operational robustness of the integrated energy system under uncertainty.

5. Conclusion

This study proposes a two-stage CVaR-based scheduling model for an integrated energy system incorporating renewable generation, battery storage, hydrogen storage, and demand response. The model considers renewable generation and load uncertainties while balancing expected operating cost and tail-risk cost.

The results show that the coordinated configuration achieves the best overall performance among the five cases. Compared with the no-storage case, the proposed case reduces the weighted objective by 21.56%, the expected operating cost by 20.15%, and the CVaR cost by 22.82%. Battery storage efficiently manages short-term power fluctuations, whereas hydrogen storage supports longer-duration energy shifting. Demand response further improves system flexibility by transferring loads away from peak and high-cost periods. Their coordinated operation reduces renewable energy curtailment, grid dependence, and exposure to high-cost scenarios.

Overall, the proposed strategy provides an effective approach for improving the economy, renewable energy accommodation capability, and operational robustness of integrated energy systems under uncertainty. Future research may consider equipment degradation, multi-day scheduling, forecast correlations, and real-time operation to further enhance the practical applicability of the model.

Disclosure statement

The author declares no conflict of interest.

Reference

[1] Li B, Chen M, Zhong H, et al., 2023, A Review of Long-Term Planning of New Power Systems with Large Share of Renewable Energy. Proceedings of the CSEE, 43(2): 555–581.

[2] Zhuo Z, Zhang N, Xie X, et al., 2021, Key Technologies and Development Challenges of Power Systems with High Proportion of Renewable Energy. Automation of Electric Power Systems, 45(9): 171–191.

[3] Liu Z, 2026, Research on Future Development Path of Renewable Energy: Analysis Based on Renewable Energy Consumption Responsibility Weight and Green Power Direct Connection Policy. China Energy Observation, 2026(2): 92–96.

[4] Yang Z, Cao J, Shi Y, et al., 2026, Capacity Allocation Optimization of Wind-Solar-Load-Storage for Grid-Connected Green Power Direct Supply Projects Considering Load-Side Response. Northwest Hydropower, 2026(2): 124–130.

[5] Zhao D, An Y, Sun Z, et al., 2026, Research on Optimization and Scheduling Technology of Green Power Direct Connection System for AIDC Computing Power Base. Journal of Electric Power: 1–11.

[6] Ding H, Shang H, Tao Y, et al., 2026, A Review on Scheduling Optimization of Source-Grid-Load-Storage

Integrated System. Journal of Chinese Society of Power Engineering, 46(5): 50–63.

[7] Lin W, Jiang R, Ren X, 2026, Definition and Key Collaborative Technologies for Electricity-Hydrogen-Carbon Ecosystem. Power System Technology: 1–19.

[8] Zhang B, Cai Y, Liu D, et al., 2025, An Intelligent Regulation Solution for Integrated Wind-Solar-Storage and Power-Hydrogen-Ammonia Coupling Systems. Automation Panorama, 42(10): 54–57.

[9] Huang Z, Wen Z, Wang C, 2025, Optimal Scheduling of Integrated Energy System Considering Multiple Utilization of Ammonia Energy. Modern Electronics Technique: 1–6.

[10] Wang S, Hu S, Cheng D, et al., 2026, Two-Stage Distributionally Robust Scheduling of Off-Grid Wind-Solar-Hydrogen-Ammonia Systems Adopting Multi-State Flexible Synthesis. Journal of Xi'an Jiaotong University: 1–10.

[11] Cheng J, Zhang B, Bao G, 2025, Two-Stage Optimal Scheduling Strategy for Hydrogen-Electric-Thermal Multi-Energy Coupled Hybrid Hydrogen Production Integrated Energy System. Southern Power System Technology: 1–12.

[12] Wang R, Liu J, Ju W, et al., 2025, Coordinated Optimal Scheduling of Electric-Hydrogen System Considering Hybrid Energy Storage in the Day-Ahead and Intra-Day Stages. Journal of Shandong University (Engineering Science): 1–9.

[13] Xu Z, Sun Y, Xie D, et al., 2020, Optimal Energy Storage Configuration of Regional Integrated Energy System Considering Electric/Thermal Flexible Loads. Automation of Electric Power Systems, 44(2): 53–59.

[14] Qi N, Cheng L, Tian L, et al., 2020, Review and Prospect of Distribution Network Planning Considering Flexible Load Integration. Automation of Electric Power Systems, 44(10): 193–207.

[15] Zhang J, Lyu H, Hu S, et al., 2026, Low-Carbon Optimization Scheduling of Electric-Thermal Integrated Energy System Considering Uncertainty of Flexible Loads. Machine Building & Automation, 55(1): 213–217.