Operational Planning for Integrated Energy System with Carbon Flow and Trading Scheme Towards Emission Reduction

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Abstract

The operational planning for Integrated Energy System (IES) with different energy carriers provides a new perspective of synergies towards a low-carbon society. Existing carbon trading scheme promotes this process via finical incentives. However, as customers are the underlying driver of emission. Planning with accurate carbon tracing and demand response would improve the effective of decarbonization. Meanwhile, customers would be encouraged to participate with extra environmental profits rather than passive price taker, under the double taxation principle. Therefore, a forward cycle can be established to reduce carbon emission. This paper proposes an operation planning model for IES to study the influence of demand response to emission mitigation and system dispatch in both energy market and carbon trading market. The proposed model is tested on an IES system involving a modified IEEE 24-bus electricity network and modified 20-bus natural gas network. Based on the simulation result, the proposed model is effective to achieve emission mitigation.

Keywords—: integrated energy system, low-carbon economy, emission trading market, carbon emission flow, demand response

Introduction

Integrated Energy System (IES) is considered to be the most mainstream energy form during the process of synergies, it can enable multiple energy carriers with different characteristics participating in the energy supply chain. There different characteristics consist of various aspects including economy, delivery, storage etc., which provides more flexible options in operational planning. For instance, comparing to electricity power, natural gas has showed obvious better performance in energy storage and carbon emission during the combustion process. However, based on the mature network and market principle, electricity power has advantages in economic aspect. Under the definition of low-carbon society, IES has potential in emission mitigation covering from the whole energy supply chain from primary energy sources to end-use customers. Therefore, how to plan the operation of IES toward emission reduction attracts more and more attention.

As for the carbon policies, carbon trading scheme is considered as one of most effective and fair methods by using financial incentives to encourage emission mitigation. he total European Union emission has decreased by 5.9% from combustion installation between 2017 and 2018. the main reason is caused by the phasing out coal use in power plants. Meanwhile, the total emission reduction made approximately EUR 14.1 billion revenue from auctions. active customers would be encouraged to participate with extra environmental profits rather than passive price taker. It can establish a forward cycle to more effectively reduce carbon emission.

This paper proposes a coordinated operation planning model for IES to study the influence of demand response to emission mitigation and system dispatch in both energy market and carbon trading market. Moreover, optimal installed renewable generators including PV, wind are also considered.

Methodology

A. Carbon Emission (CEF) Model in IES

A concept of "carbon emission flow (CEF)" has been introduced to reveal the relationship between energy flow and accompanying carbon emission. In this paper, we utilize this methodology to trace the carbon emission in IES. Mathematically, the CEF model can be expressed as:

$$e_{i,t}^{(\bullet)} = \frac{\sum\limits_{n\in\Omega_{Gi}^{(\bullet)}} P_{Gn,t}\cdot e_{Gn}^{(\bullet)} + \sum\limits_{j\in\Omega_i^{f^+}} \left|S_{ij,t}^{(\bullet)}\right|\cdot\rho_{ij,t}^{(\bullet)}}{\sum\limits_{n\in\Omega_{Gi}^{(\bullet)}} P_{Gn,t} + \sum\limits_{j\in\Omega_i^{f^+}} \left|S_{ij,t}^{(\bullet)}\right|}$$

$$\rho_{ij,t}^{(\bullet)} = \begin{cases} e_{i,t}^{(\bullet)}, & if\ \ S_{ij,t}^{(\bullet)} \ge 0 \\ e_{j,t}^{(\bullet)}, & if\ \ S_{ij,t}^{(\bullet)} < 0 \end{cases} \qquad E_{i,t}^{(\bullet)} = P_{i,t}\cdot e_{i,t}^{(\bullet)}\cdot\Delta t$$

B. Principle

- Firstly, the *double taxation principle* is applied to the proposed model to clearly identify the responsibility of carbon emission from both supply side and demand side.
- Secondly, the cap-and-trade principle of carbon trading scheme is used in proposed model.
- Finally, a zero sum gains-data envelopment analysis (ZSG-DEA) model introduced is utilized to allocate the carbon emission allowance at demand side. Furthermore, developed multiple indicators for the ZSG-DEA has been rearranged aiming particularly on the energy sector. In the ZSG-DEA model, *equity*, *efficiency*, *feasibility* and *sustainability* principles are employed.

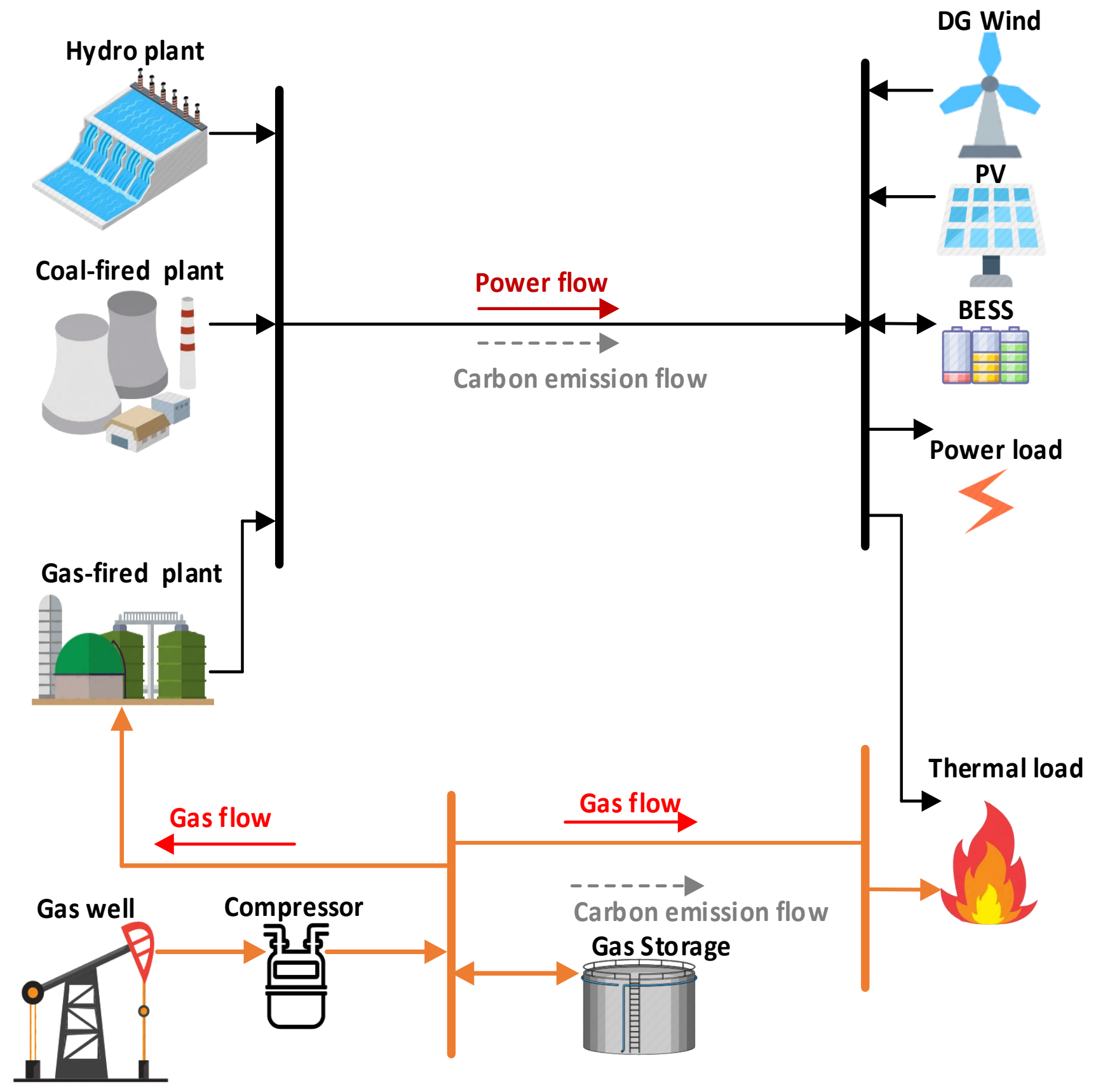

Fig. 1. Paradigm of integrated energy system with renewable generation

C. Details of Proposed Model

The overall proposed framework is modelled as a two-stage optimization problem. At the first stage, the objective is formulated to maximize the overall social welfare in the integrated energy market and potential environmental welfare from the perspective of supple side, for a period of operation planning collated to the time-interval of allocated emission (e.g. One season). Based on the energy price and nodal carbon intensity, at the second stage, the formulated objective function aims to maximize the total consumer surplus in energy market and potential environmental profits in carbon trading market for the same time-interval as stage one.

$$\max\ S^{Ele} + S^{Ele} + S^{Env} = \min - (S^{Ele} + S^{Ele} + S^{Env})$$

$$S^{Ele} = \sum\sum_{t=1}^{T^{Ele}}[\sum_{\substack{j\in\Omega_D^{Ele}\\ m\in\Omega_D^{Ele,Gas}}} U^{Ele}(P_{Dj,t}, P_{Dm,t}) - \sum_{i\in\Omega_G^{Ele}} C^{Ele}(P_{Gi,t}) - \sum_{i\in\Omega_G^{Gas-fired}} C^{Gas-fired}(P_{Gi,t}^{Gas})]$$

$$S^{Env} = \sum_{i\in\Omega_G^{Ele}} \lambda_i^{Carbon}\cdot(E_{Gi}^{Cap} - \sum\sum_{t=1}^{T^{Ele}} E_{Gi,t}) \qquad C^{Ele}(P_{Gi,t}) = a_{Gi}\cdot P_{Gi,t}^2 + b_{Gi}\cdot P_{Gi,t} + c_{Gi}$$

$$C^{Gas-fired}(P_{Gi,t}^{Gas}) = a_{Gi,t}^{Gas-fired}\cdot P_{Gi,t}^{Gas^2} + b_{Gi,t}^{Gas-fired}\cdot P_{Gi,t}^{Gas} + c_{Gi,t}^{Gas-fired}$$

In this paper, a piecewise function is employed as utility function to model the satisfaction of customers related to energy purchase and energy utilization.

$$U^{(\bullet)}(P_{Di,t}) = \begin{cases} b_i^{(\bullet)}\cdot(P_{Dj,t}, P_{Dm,t}) - a_i^{(\bullet)}\cdot(P_{Dj,t}, P_{Dm,t})^2, \\ P_{Dj,t} + P_{Dm,t} < \dfrac{b_i^{(\bullet)}}{2a_i^{(\bullet)}} \\ \dfrac{(b_i^{(\bullet)})^2}{2a_i^{(\bullet)}}, \quad P_{Dj,t} + P_{Dm,t} \ge \dfrac{b_i^{(\bullet)}}{2a_i^{(\bullet)}} \end{cases},$$

$$\forall t\in 1:T, \forall j\in\Omega_D^{Ele}, \forall m\in\Omega_D^{Ele,Gas}, \forall i\in\Omega_D^{Ele}/\Omega_D^{Ele,Gas}$$

$$\max\ \underbrace{(U_D^{Ele} - C_D^{Ele}) + (U_D^{Gas} - C_D^{Gas})}_{Consumer\ surplus\ in\ integrated\ energy\ market} + R^{DG} - C^{DG} + R_D^{Env}$$

$$R^{DG} = \sum_{t=1}^{T^{Ele}}\sum_{i\in\Omega^{Ele}} P_{i,t}^{DG}\cdot\lambda_{i,t}^{Ele}\cdot\Delta t \qquad C^{DG} = \sum_{i\in\Omega_{DG}^{PV}} C^{PV} + \sum_{i\in\Omega_{DG}^{Wind}} C^{Wind} + \sum_t^{T^{Ele}}\sum_{i\in\Omega^{BESS}} C_{i,t}^{BESS}$$

$$R_D^{Env} = [\sum_{j\in\Omega_D^{Ele}} \lambda_j^{Carbon}\cdot(\sum\sum_{t=1}^{T^{Ele}} E_{Dj,t} - E_{Dj}^{Cap}) + \sum_{m\in\Omega_D^{Ele,Gas}} \lambda_m^{Carbon}\cdot(\sum\sum_{t=1}^{T^{Ele}} E_{Dm,t} - E_{Dm}^{Cap\_mix})]$$

In this paper, superscript $(\bullet)$ consists of Ele and Gas, formulations for gas network can be obtained by replacing P by g. Detailed constraints can be found at the submitted paper.

Experiment

The proposed planning model is verified using the following cases:

Case 1: Conventional energy scheduling with price-based demand response without carbon trading policy.

Case 2: Proposed two-stage planning model with price-based demand response and optimizing renewable generation installation at customer side. The *sequential quadratic programming* (*SQP*) is applied to solve the two-stage nonlinear optimization problem on Matlab® by a PC with an Intel Core (TM) i7-8700 CPU @3.20GHz with 16.00 GB RAM.

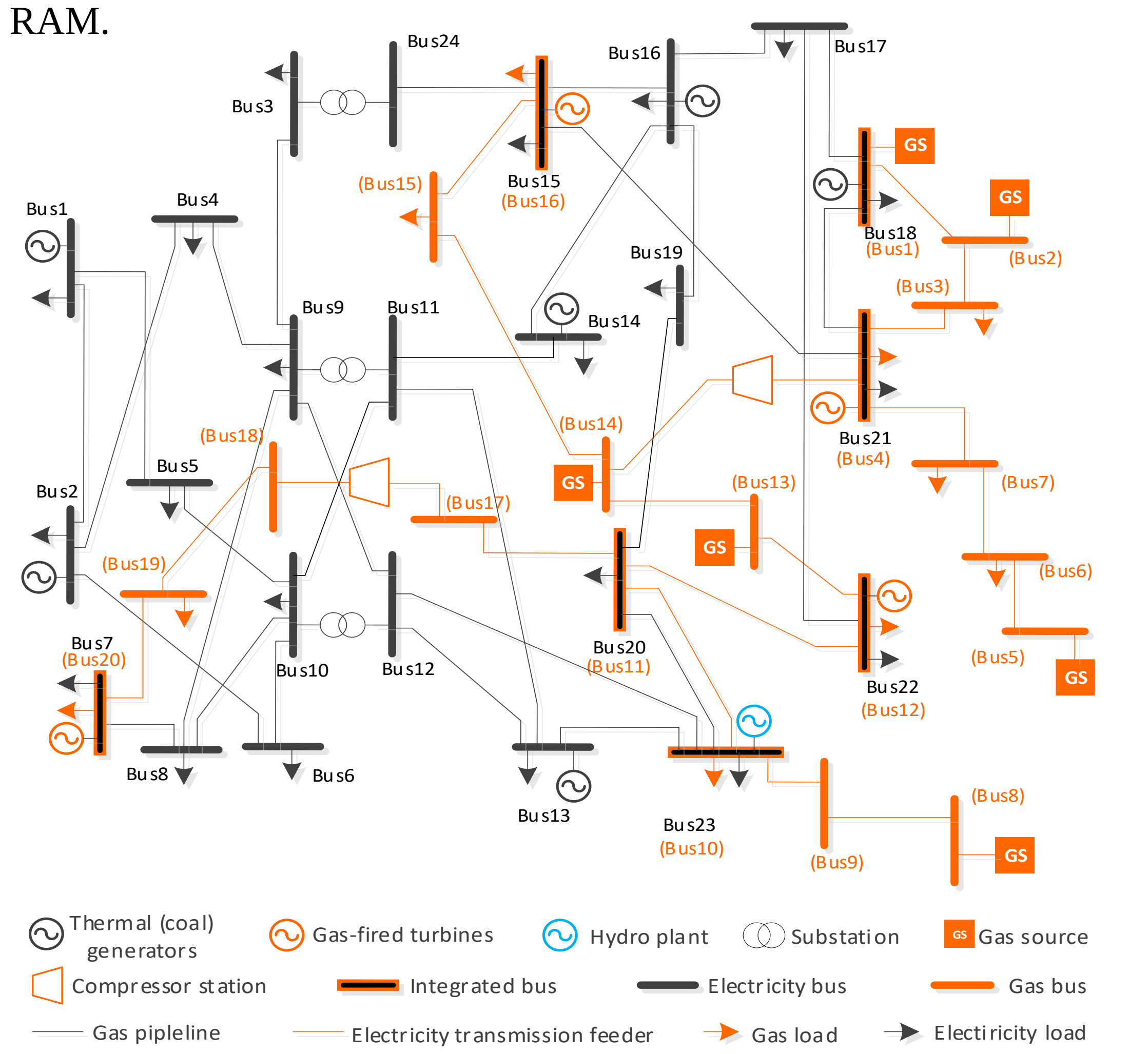

Fig. 2. Tested IES with modified electricity and gas network

Results

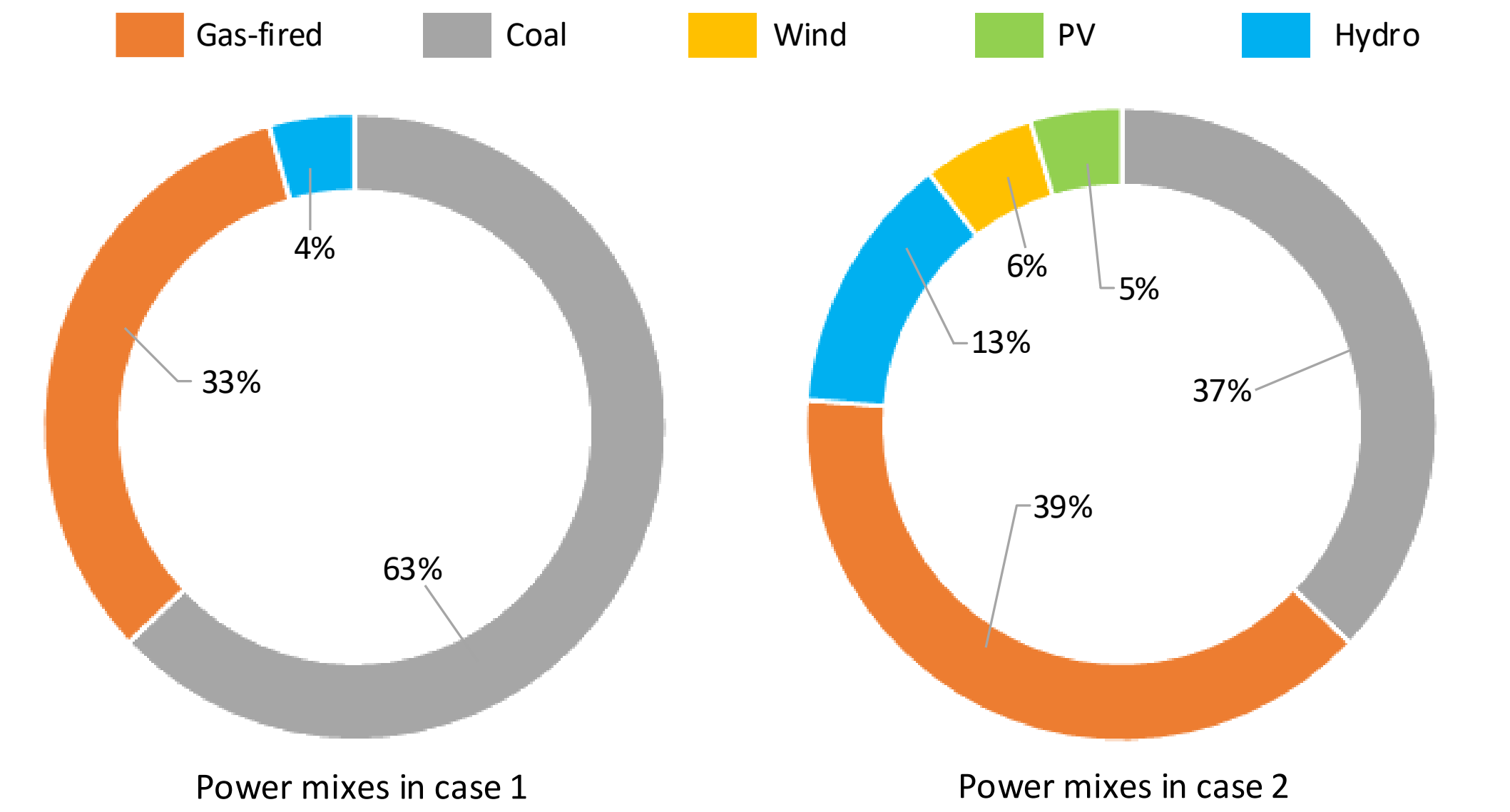

Fig. 3. Detailed power mixes in cases for electricity network in IES

Detailed power mixes in different cases are shown in Fig. 3. It can be seen there is a significant decrease of power output produced by coal generators in total power consumption from case 1 to case 2, the value is around 26%. Meanwhile, the proportion of power from hydro plant has the biggest increase, the value changes from 4% to 13%. As aforementioned, the usage of power from gas-fired generators increase about 6% of power proportion. Distributed generators totally hold 11% percent in total power output, herein, 5% is from PV, 6% is from wind generators.

The power demand changing between case 1 and case 2 is shown in Fig. 4. Compared to case 1, the demand curve becomes smoother in case 2. Moreover, there is about 40% demand reduction by active participation of customers. Except the increasing power out from clean energy, demand response is also the reason why so much emission decreased in case 2.

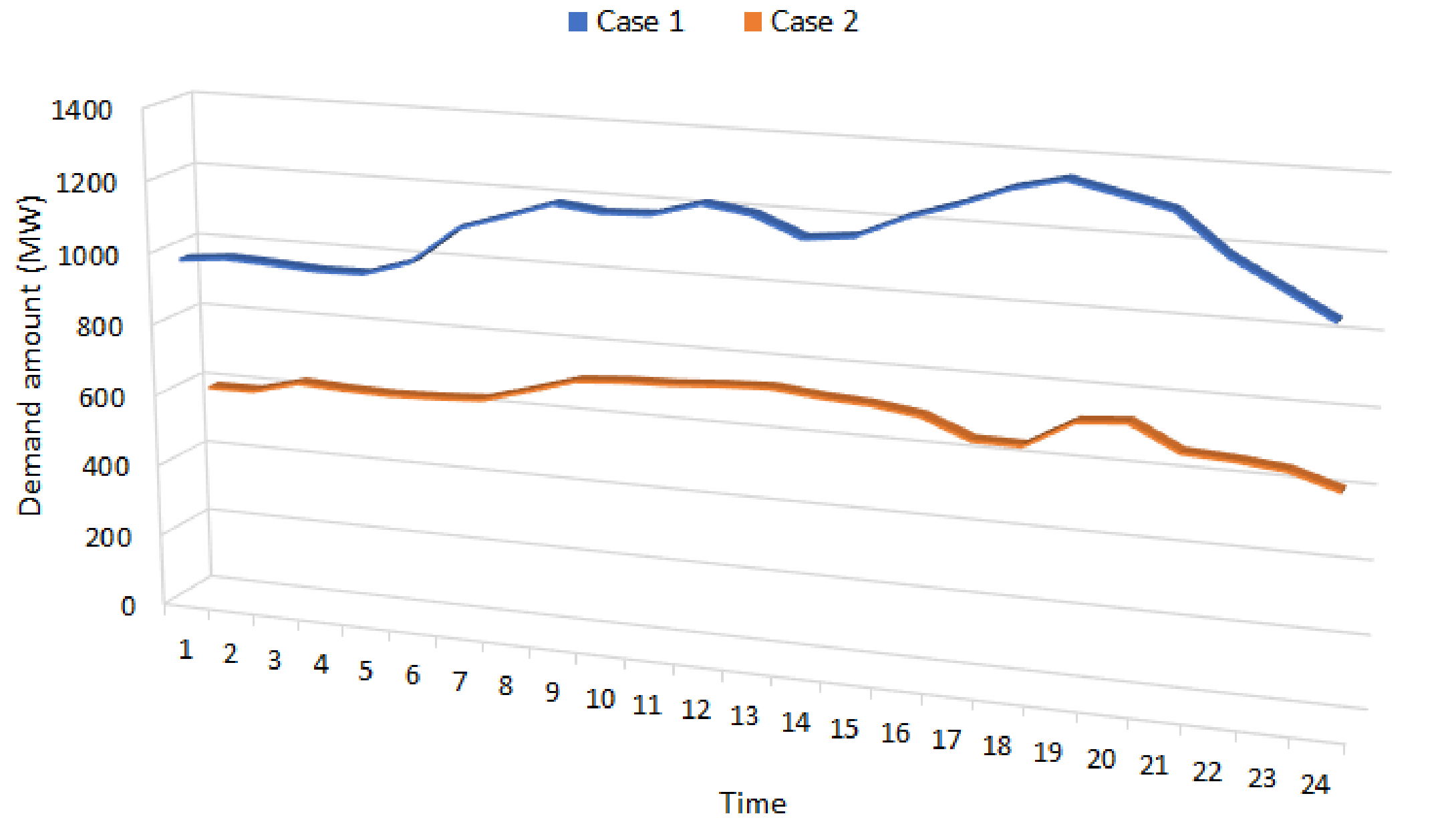

Fig. 4. Total power demand changing comparison in one typical day

Conclusion

This paper proposes an operation planning model for IES to study the influence of demand response to emission mitigation and system dispatch in both energy market and carbon trading market. Case studies show that the proposed model can achieve emission mitigation effectively. This model can a guide for energy source companies and energy, carbon market operators.

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