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Impact of Compressor Coordination on Linepack Optimization and Cost Reduction for 24-Hour Operation in Integrated Gas and Electricity Network

Mohammad Mehdi Amiri[1,*], Mohammad Taghi Ameli[1], Mohammad Reza Aghamohammadi[1]

[1] *Department of Electrical Engineering, Shahid Beheshti University, Tehran, Iran*

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ABSTRACT

The integration of gas and electricity networks is pivotal for efficient energy management, particularly with the rising penetration of renewable energy sources. Compressor stations are critical for maintaining gas pressure and flow, and their optimal operation can significantly enhance system flexibility and reduce costs. While previous studies have explored coordinated operation of compressor units, this research introduces a novel price-responsive coordination strategy for compressor stations comprising both gas-driven compressors (GDCs) and electric-driven compressors (EDCs) within an integrated gas and electricity network. The proposed strategy operates GDCs when gas prices are lower and EDCs when electricity prices are lower, aiming to optimize linepack storage in gas pipelines. Using a mixed-integer linear programming (MILP) model, we optimize the scheduling of compressors based on hourly energy prices while ensuring network constraints are met. Simulations on a 24-bus electricity and 19-node gas network over a 24-hour period demonstrate that this coordinated approach leads to a substantial increase in linepack storage and a reduction in operational costs compared to uncoordinated operation. Simulation results show that in the proposed design, i.e., by integrating the optimized linepack model into the compressor station model, the amount of carbon dioxide produced has decreased by 33.3% and the total operation costs have decreased by 1.57%.

Abbreviation

RES	Renewable energy sources
IGEN	Integrated gas and electricity networks
VREs	Variable renewable energy sources
EPS	Electric power systems
NGN	Natural gas networks
MILP	Mixed-integer linear programming
SOCP	Second-order cone programming
DRO	Distributionally robust optimization
MIP	Mixed-integer programming
GDCs	Gas-driven compressors
EDCs	Electric-driven compressors
MISOCP	Mixed-Integer Second Order Cone Programming
NLP	Nonlinear program ming
GFPPs	Gas-fired power plants

* Corresponding author
E-mail address: moh_amiri@sbu.ac.ir
https://orcid.org/0000-0002-4813-1849
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1. Introduction

1.1. Motivation and background

The global energy landscape is undergoing a profound transformation, driven by the urgent need to decarbonize and integrate renewable energy sources (RES) into existing infrastructures. Integrated gas and electricity networks (IGEN) have emerged as a pivotal framework to address the challenges posed by the high penetration of variable renewable energy sources (VREs), such as wind and solar power. By coupling electric power systems (EPS) with natural gas networks (NGN), IGEN facilitate efficient energy flow management, leveraging technologies like Power-to-Gas (PtG) to convert surplus renewable electricity into gaseous fuels, such as hydrogen or synthetic methane. This integration not only supports the decarbonization goals outlined in the Paris Agreement, aiming to limit global temperature rise to below 2°C, but also optimizes the utilization of existing infrastructure, reducing operational costs and greenhouse gas emissions. Projections indicate that the share of RES in global energy consumption is expected to reach 57% by 2030 and 86% by 2050, necessitating advanced strategies to mitigate the variability and uncertainty associated with renewable generation [1]. In 2021, Europe invested 41 billion euros in wind power, adding 24.6 GW of capacity, underscoring the rapid growth of renewables and the need for integrated networks to manage their intermittency [2].

A critical component of gas network operation within IGEN is the concept of linepack, defined as the volume of gas stored within pipelines, which acts as a virtual storage mechanism. Linepack enables operators to balance supply and demand without immediate adjustments in production or consumption, providing a cost-effective solution to manage the intermittency of VREs. By storing excess gas during periods of high renewable generation and releasing it during peak demand, linepack enhances system flexibility and resilience. Recent studies have developed sophisticated mathematical models, such as mixed-integer linear programming (MILP) and second-order cone programming (SOCP), to optimize linepack utilization while ensuring pressure and flow constraints are maintained [3, 4]. For instance, Wu et al. [4] proposed a two-stage distributionally robust optimization (DRO) model that incorporates linepack and P2G to manage renewable uncertainties, achieving a 15% reduction in carbon emissions and enhanced system resilience. Similarly, [5] highlighted that linepack can provide up to 20% of pipeline capacity as storage in systems like the UK gas network, demonstrating its critical role in integrated energy networks. These models often linearize the nonlinear Weymouth equation to ensure computational tractability, providing a robust framework for enhancing system efficiency. [6] presents a two-stage optimal dispatch model for IGEN, explicitly considering natural gas pipeline leakage and linepack. Using mixed-integer programming (MIP) and the column-and-constraint generation (C&CG) method, the model optimizes the joint benefits of electricity and gas suppliers under worst-case scenarios. [7] examines how modeling methods (dynamic/DY, steady-state/ST) and solution methods quantify linepack flexibility in mitigating wind power variability. Case studies demonstrate that DY model, which preserve transient flow physics through PDE discretization and pressure-flow coupling, reduce operating costs by 37.5% compared to ST models ignoring dynamics.

On the other hand, compressors are indispensable for maintaining the pressure and flow of gas in pipelines, particularly over long distances, and their operation significantly influences linepack levels. In IGEN, compressors can be powered by either gas (GDCs) or electricity (EDCs), each with distinct operational characteristics and cost implications. The choice between GDCs and EDCs depends on factors such as energy prices, efficiency, and environmental impact. Coordinating the operation of these compressors based on real-time energy prices can lead to significant cost savings and improved system efficiency. For example, operating EDCs when electricity prices are low and GDCs when gas prices are favorable optimizes energy consumption and enhances linepack storage. Recent research by Saedi et al. [5] explored the role of flexibility in low-carbon IGEN, emphasizing technologies like linepack and PtG in facilitating renewable integration and demand-side management. However, traditional compressor operation strategies often rely on fixed schedules, neglecting the dynamic nature of energy prices, which leads to suboptimal linepack utilization and increased costs [8].

In [9], the optimal operation of GDCs and EDCs was investigated to minimise the cost of operating a gas network. The operational optimisation model of the gas network with relatively detailed representation of gas compressors was formulated as a Mixed-Integer Second Order Cone Programming (MISOCP) problem. A bound-tightening algorithm was used to improve the quality of the solution from the relaxed MISOCP formulation. Using this model, the operation of the high-pressure gas transmission network in South Wales and Southwest of England was optimised considering day-ahead gas and electricity prices. [10] presents two standby scheme optimization models considering various normal and failure scenarios for two standby modes: unit standby and power standby, respectively. The proposed models aim to maximize the gas delivery reliability subjected to rigorous operating constraints of a gas pipeline system and budget constraints (e.g., the total amount of standby power/ units). The resultant optimization models for power standby and unit standby schemes are large-scale nonlinear program ming (NLP) and mixed-integer nonlinear programming (MINLP), respectively.

1.2. Research gaps in operation of IGEN

Despite the advancements in IGEN modeling, there remains a significant research gap in the price-responsive coordination of GDCs and EDCs to optimize linepack storage. Most studies focus on uniform compressor operation or static scheduling, overlooking the potential of dynamic coordination based on hourly energy prices.

For example, in [11], co-operation of the integrated network is carried out with the aim of increasing flexibility, in which hydrogen storage and electric vehicle parking are carried out with a load shift approach. The performance of the compressors as well as the linepack model are ignored. [12] proposes an optimal dispatch method for integrated electricity and gas systems incorporating hydrogen injection. A hydrogen blending transmission model is developed for hydrogen enriched compressed natural gas. The dynamic characteristics and the line pack are captured considering the impacts of hydrogen injection on pipeline transmission and line pack parameters. The role of compressors in increasing linepack was not seen in this study. In [13], IGEN optimization is studied. The excitation of the compressors in this study is considered only electrically and linepack modeling is performed. The evaluation of IGEN flexibility considering the role of compressors in linepack enhancement is studied in [14]. The coordinated approach of compressors and their switchable excitation capability is ignored in this study. The operation of an integrated network with a cost reduction approach has been carried out in [15]. Modeling the electricity, gas and heat markets has the strength of this study, while attention to the parameters in the network and detailed network modeling, including modeling the linepack in gas pipes and the impact of price fluctuations in the market, has not been seen in this study. The precise modeling of the coordinated operation of compressors in the form of a compressor station has been studied in [8]. The role of the compressor station in reducing carbon emissions and operating costs has been proven in this paper, however, the lack of modeling of linepack in the function of this equation can be considered as a study gap in this paper.

This study addresses this gap by proposing a novel coordination strategy that leverages price signals to schedule GDCs and EDCs within a compressor station, aiming to maximize linepack storage and minimize operational costs over a 24-hour period. By integrating this strategy into a MILP model, tested on a standard 24-bus electricity and 19-node gas network, this research seeks to provide actionable insights for IGEN operators. The proposed approach not only enhances the economic performance of IGEN but also contributes to the broader goal of sustainable energy systems by improving flexibility and reducing carbon emissions.

The remainder of this paper is organized as follows. After Section 1, the structure of IGEN is presented in Section 2, Mathematical modeling, formulation, and problem-solving methodology are presented in Section 3, Section 4 includes simulations and numerical results, and finally, a summary of the findings and suggestions for future work are included in Section 5.

2. IGEN configuration

In this study, a standard 24-bus IEEE power grid and a 15-node gas grid are used. The connection between the two grids is through gas-fired power plants (GFPPs), of which 3 are considered. Two of these generators are connected to node 6 and the other to node 8 of gas network. A compressor station is assumed between nodes 15 and 2. The network parameters are extracted from references [16,17]. Fig.1 shows the IGEN configuration under study. Fig.2 showes the gas and electricity prices for 24 hours [8]. The gas price is fixed as £185/kcm, which is equivalent to 17.08 £/MWh.

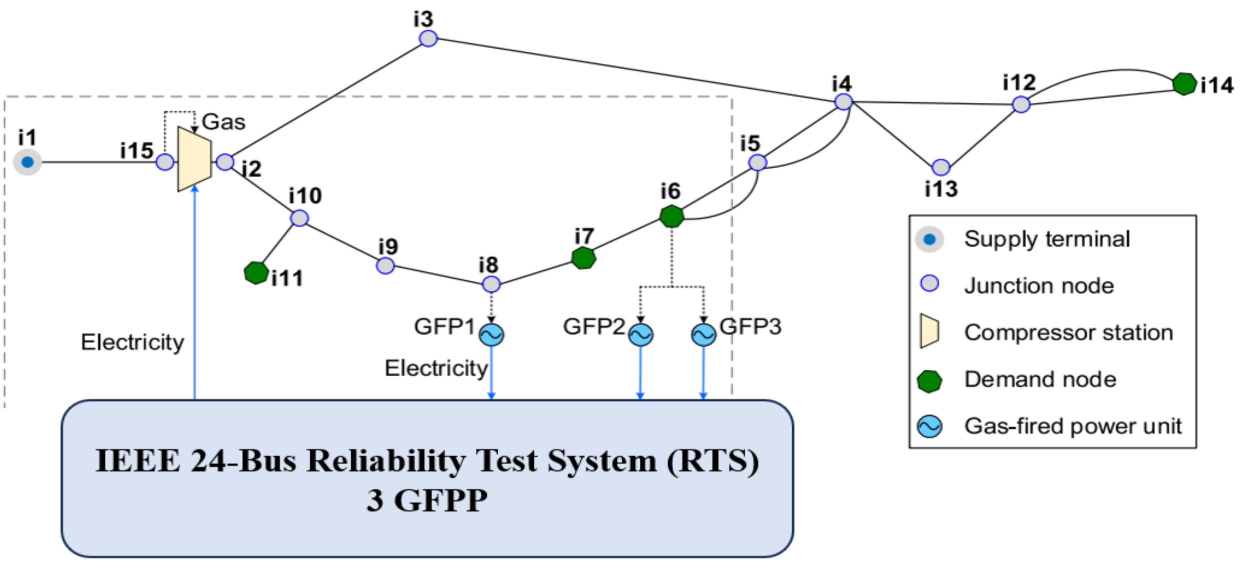

Fig.1. Configuration of IGEN under study

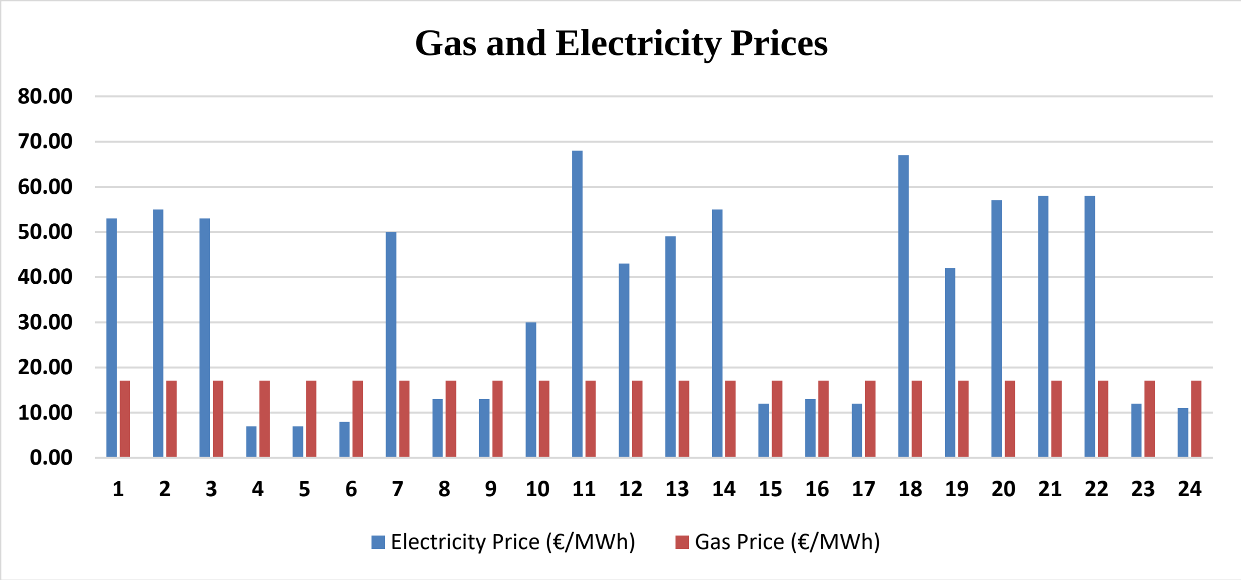

Fig.2. Prices for gas and electricity

3. Mathematical Formulation

3.1. *Objective function*

The objective function minimizes the total operational cost of the integrated network over the scheduling horizon T , including [8]:

- Cost of gas supply,
- Cost of electricity consumption by EDCs,
- Revenue from gas-fired power plants (GFPPs).

$$\min \sum_{t \in T} \left(\begin{array}{l} \sum_{s \in S} C_t^G \cdot Q_{s,t}^S + \sum_{ec \in EC} C_t^E \cdot P_{ec,t}^C \\ -\sum_{e \in E} C_t^E \cdot P_{e,t} \end{array} \right) \tag{1}$$

Where,

h : time step duration (e.g., 1 hour)

C_t^G : gas price at time t [\$/kcm]

C_t^E :electricity price at time t [\$/MWh]

$Q_{s,t}^S$: gas supply from terminal s [kcm/h]

$P_{ec,t}^C$: power consumption of EDC unit ec [MW]

$P_{e,t}$: power generation from GFPP e [MW]

This objective function captures the economic trade-off between using electricity or gas for compressor operation, based on real-time price signals.

3.2. *Gas Flow and Linepack Modeling*

The nonlinear relationship between gas flow and nodal pressures is approximated using the Weymouth equation , linearized via piecewise linearization:

$$q_{ij,t}^2 = K_{ij}^2 \cdot (\pi_{i,t} - \pi_{j,t}) \qquad (2) \tag{2}$$

Where;

$q_{ij,t}$: gas flow in pipeline (i,j) [kcm/h]

$\pi_{i,t}, \pi_{j,t}$: squared gas pressures at nodes i and j

K_{ij} : Weymouth constant for pipeline (i,j)

3.2.1. Bidirectional flow representation

Equation 3 and 4 allow the model to capture gas flow reversals due to sudden changes in demand or generation. To model bidirectional flow, binary variable $x_{ij,t} \in \{0,1\}$ is introduced:

$$q_{ij,t} = q_{ij,t}^+ - q_{ij,t}^- \tag{3}$$

$$0 \le q_{ij,t}^+ \le M \cdot x_{ij,t}, \quad 0 \le q_{ij,t}^- \le M \cdot (1 - x_{ij,t}) \tag{4}$$

Where:

$q_{ij,t}^+, q_{ij,t}^-$: Forward and reverse gas flow in pipeline (i,j)

$x_{ij,t} \in \{0,1\}$: Binary flow direction

M : a large positive constant

3.2.2. Linepack dynamics

The linepack $l_{ij,t}$, which represents the volume of gas stored in a pipeline, is modeled as:

$$l_{ij,t} = S_{ij} \cdot \frac{\pi_{i,t} + \pi_{j,t}}{2} \tag{5}$$

$$l_{ij,t} = l_{ij,t-1} + q_{ij,t}^{in} - q_{ij,t}^{out} \tag{6}$$

$$L_{ij} \le l_{ij,t} \le \overline{L}_{ij} \tag{7}$$

$$l_{ij,T} \ge l_{ij,0} \tag{8}$$

Where:

S_{ij} : linepack coefficient [kcm/bar]

$L_{ij}, \overline{L}_{ij}$: Lower and upper bounds of linepack in pipeline (i,j)

$l_{ij,0}, l_{ij,T}$: Initial linepack and final linepack at the end of the scheduling horizon

Equation (5) links linepack to average nodal pressure, while (6) ensures mass conservation. Constraints (7) and (8) ensure operational feasibility and preserve minimum linepack at the end of the scheduling period.

3.3. Compressor coordination formulation

3.3.1. Pressure boosting equation

$$\pi_{j,t} = \Gamma_t \cdot \pi_{i,t} \tag{9}$$

Where:

Γ_t : Compression ratio at time t

$\pi_{i,t}, \pi_{j,t}$: Inlet and outlet pressures of the compressor station

Equation (9) ensures that the compressor station boosts the pressure to maintain required levels for gas transport, in other words, it maintains reliability.

3.3.2. Mass conservation at compressor station

The total gas flow into and out of the compressor station is governed by:

$$q_t^{in} = \sum_{gc \in GC} Q_{gc,t} + q_t^{out} \tag{10}$$

$$\sum_{c \in C} q_{c,t} = q_t^{out} \tag{11}$$

Where $Q_{gc,t}$ is gas use by GDCs and $q_{c,t}$ is the gas flow through compressor c . q_t^{in} and q_t^{out} are inflow and outflow gas volume at the compressor station, respectively.

3.3.3. Energy consumption of compressors

EDCs:

$$P_{ec,t}^{C} = B_{ec} \cdot q_{ec,t} \cdot (\gamma_{ec,t} - 1) \tag{12}$$

GDCs:

$$Q_{gc,t} = \lambda \cdot B_{gc} \cdot q_{gc,t} \cdot (\gamma_{gc,t} - 1) \tag{13}$$

Where $P_{ec,t}^{C}$ is electricity demand of EDC unit ec . $Q_{gc,t}$ is the gas consumption of GDC unit gc , B_{ec}, B_{gc} are efficiency coefficients of compressors. λ is conversion factor from electricity to gas. All equations for compressor operation modes presented in [8].

3.3.4. Unit commitment of compressors

To manage the coexistence of EDCs and GDCs , the following constraints are applied:

$$\omega_{ec,t} \le \xi_t^{EC} \le \sum_{ec \in EC} \omega_{ec,t} \tag{14}$$

$$\omega_{gc,t} \le \xi_t^{GC} \le \sum_{gc \in GC} \omega_{gc,t} \tag{15}$$

$$\xi_t^{EC} + \xi_t^{GC} \le Z \tag{16}$$

ξ_t^{EC} and ξ_t^{GC} are binary variables indicating whether EDCs or GDCs are active, and Z is the maximum number of compressor types allowed to operate simultaneously. Constraint (16) ensures that the compressor station can operate with either EDCs or GDCs, or both, depending on the value of Z .

3.4. Gas-fired power generation

$$P_{e,t} = \phi_G \cdot H \cdot Q_{e,t}^{G} \tag{17}$$

$$\underline{P}_e \le P_{e,t} \le \overline{P}_e \tag{18}$$

Where, ϕ_G is the thermal efficiency of gas turbine, H is Heating value of natural gas, and $Q_{e,t}^{G}$ is the gas consumption of GFPP e at time t. $\underline{P}_e$ and $\overline{P}_e$ are the minimum and maximum power generation limits [8].

3.5. Solution method

Fig.3 showes the roadmap for solution of this paper.

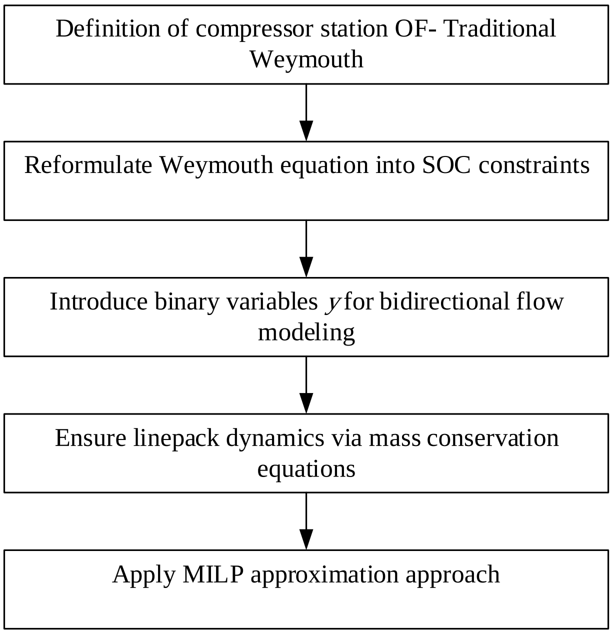

Fig.2. Flowchart of solution method

3.5.1. Directionality constraints for bidirectional flow

To accurately capture bidirectional flow in gas pipelines, we introduce binary variables $y_{m,u,t} \in \{0,1\}$, where $y_{m,u,t} = 1$ indicates flow from node m to u , and $y_{m,u,t} = 0$ implies reverse flow.

The directional flow constraints are modeled as:

$$-M \cdot (1 - y_{m,u,t}) \le q_{m,u,t} \le M \cdot y_{m,u,t} \tag{19}$$

$$q_{m,u,t}^{+} = \frac{1}{2}(q_{m,u,t}^{\text{in}} + q_{m,u,t}^{\text{out}}), \quad q_{m,u,t}^{-} = \frac{1}{2}(q_{m,u,t}^{\text{in}} - q_{m,u,t}^{\text{out}}) \tag{20}$$

This ensures that only one of the forward or backward flows is active at any given time step, depending on the value of $y_{m,u,t}$.

3.5.2. Linepack dynamics approximation

The linepack $l_{m,u,t}$ representing the volume of gas stored in pipeline (m,u) at time t, is defined as:

$$l_{m,u,t} = S_{m,u} \cdot \frac{\pi_{m,t} + \pi_{u,t}}{2} \tag{21}$$

Where $S_{m,u}$ is the linepack constant of pipeline (m,u) [kcf/psig].

To maintain mass conservation over time, the linepack update equation is written as:

$$l_{m,u,t} = l_{m,u,t-1} + q^{\text{in}}_{m,u,t} - q^{\text{out}}_{m,u,t} \tag{22}$$

Additionally, initial and final linepack values are constrained by:

$$l_{m,u,0} = H^{0}_{m,u} \tag{23}$$

$$l_{m,u,T} \geq l_{m,u,0} \tag{24}$$

Constraint (24) ensures sufficient linepack remains at the end of the scheduling horizon to support subsequent operations.

3.5.3. MILP approximation approach

In the MILP approach, the Weymouth equation is approximated using a set of tangent planes around fixed pressure values $\Pi_{m,v}, \Pi_{u,v}$, leading to the following linearized constraints. MILP approach offers exact linearization at discrete pressure points

$$q^{+}_{m,u,t} \leq \left(\frac{\Pi^2_{m,v} - \Pi^2_{u,v}}{K_{m,u} \cdot \Pi_{m,v}} \right) \cdot \pi_{m,t} - \left(\frac{\Pi^2_{m,v} - \Pi^2_{u,v}}{K_{m,u} \cdot \Pi_{u,v}} \right) \cdot \pi_{u,t} + M \cdot (1 - y_{m,u,t}) \tag{25}$$

$$q^{-}_{m,u,t} \leq \left(\frac{\Pi^2_{u,v} - \Pi^2_{m,v}}{K_{m,u} \cdot \Pi_{u,v}} \right) \cdot \pi_{u,t} - \left(\frac{\Pi^2_{u,v} - \Pi^2_{m,v}}{K_{m,u} \cdot \Pi_{m,v}} \right) \cdot \pi_{m,t} + M \cdot y_{m,u,t} \tag{26}$$

4. Numerical results

This section presents the numerical results of the proposed MILP model for the coordinated operation of IGEN, focusing on the flexibility provided by compressor units and linepack dynamics. Three scenarios were analyzed:

- Scenario 1 : All compressors are always ON (no price-based scheduling).
- Scenario 2 : Compressors operate based on real-time electricity and gas prices.
- Scenario 3 : Price-based scheduling with additional flexibility from linepack utilization.

The simulations were conducted over a 24-hour scheduling horizon using hourly data for electricity prices and fixed gas prices. The total system cost, energy consumption, linepack variation, and CO_2 emissions were evaluated for each scenario to assess the impact of flexible compressor operation and linepack management.

5.1. Energy Consumption of Compressors

In Scenario 1, all compressors (2 GDCs and 1 EDC) are continuously active throughout the 24-hour period, resulting in the highest energy usage. In Scenario 1 , where all compressors were continuously active throughout the scheduling horizon, the system incurred the highest operational cost (£1,753,817 per day), along with the maximum gas consumption (153.6 kcm) and CO_2 emissions (276.48 kg). This scenario reflects conventional operation without price-responsive dispatch or linepack management. Fig.4 shows the revenue from GFPPs in scenario 1, over 24 hours. The average linepack stored in the pipes in this scenario is 7850 Kcm and the revenue generated is £1211472.

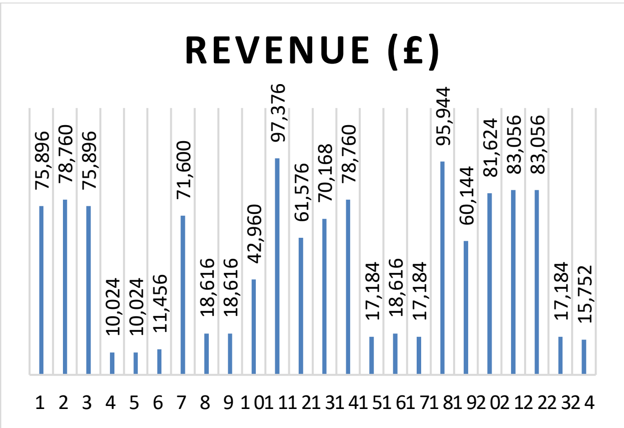

Fig.4. revenue from GFPPs; Scenario 1

In Scenario 2, compressors are scheduled based on hourly electricity prices to minimize the total system cost. During low electricity price hours (e.g., 4–6 and 15–17), the EDC is active while GDCs remain OFF. Conversely, during high electricity price periods (e.g., 7–12 and 13–15), GDCs are used to avoid expensive electricity consumption. This strategy reduces daily operational costs by 2.1%, lowers gas consumption by 50%, and decreases CO_2 emissions by 50% compared to Scenario 1. The average linepack increases due to strategic gas storage during low-price periods. The average linepack stored in the pipes in scenario 2 is 8150 Kcm and the revenue generated is £1242381.

Scenario 3 further enhances flexibility by incorporating linepack dynamics . When sufficient linepack is available, compressors can be turned OFF to reduce operational costs. This leads to a reduction in both gas and electricity consumption , especially during peak electricity price periods. The average linepack stored in the pipes in scenario 3 is 8302 Kcm and the revenue generated is £1264800. A comparison of the amount of linepack saved in the three scenarios is shown in Fig.5. As is clear, by using the optimal linepack model in the proposed scheme, the amount of linepack saved has increased. By storing gas in pipelines, it allows the system to defer compression tasks to cheaper electricity hours.Total gas (kcm) and total electricity consumption (MWh) is showed in Table.1.

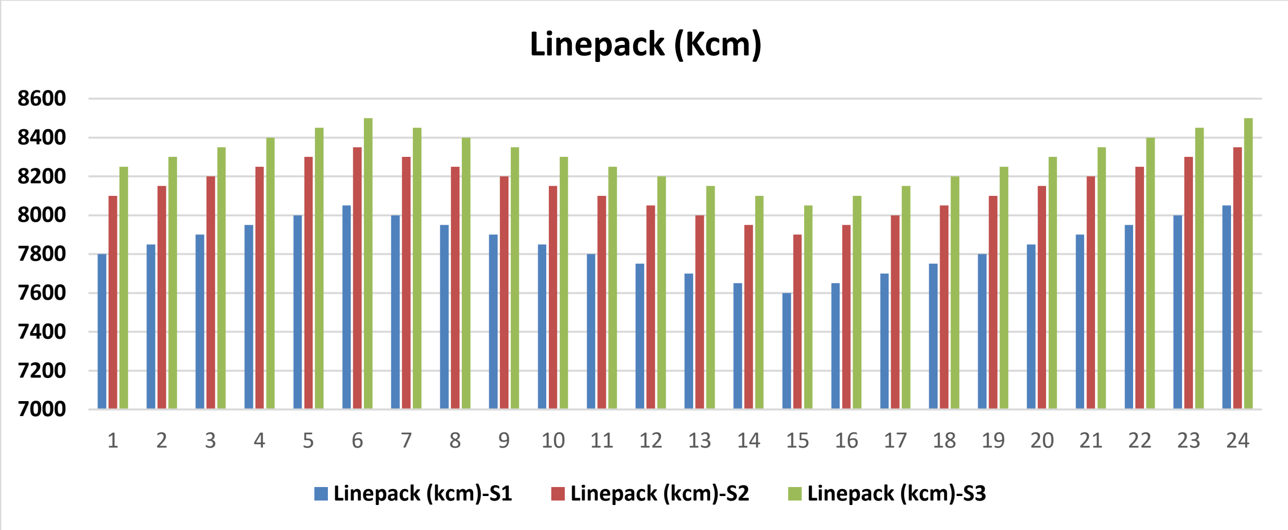

Fig.5. Linepack stored in pipelines in 3 scenarios

Table 1. Total gas (kcm) and total electricity consumption (MWh)

Scenario	Total Gas Consumption (kcm)	Total Electricity Consumption (MWh)
1	153.6	840
2	76.8	420
3	51.2	560

In Scenario 1, linepack remains relatively constant due to continuous compressor operation. However, in Scenarios 2 and 3, linepack is actively managed: it increases during low electricity price periods (via EDCs) and decreases during high-price periods (by extracting stored gas). Scenario 3 shows the most efficient use of linepack, allowing compressors to be inactive when gas demand is met through pipeline storage.

This dynamic behavior demonstrates how linepack acts as a virtual gas storage , enabling temporal shifting of gas flows and reducing the need for real-time compression.

5.3. System Cost Analysis

The total operational cost includes both gas supply costs and electricity consumption by compressors , offset by revenue from GFPPs and CO_2 production is presented in Table.2. Fig.6 shows the operation cost in 3 scenario and carbon reduction.

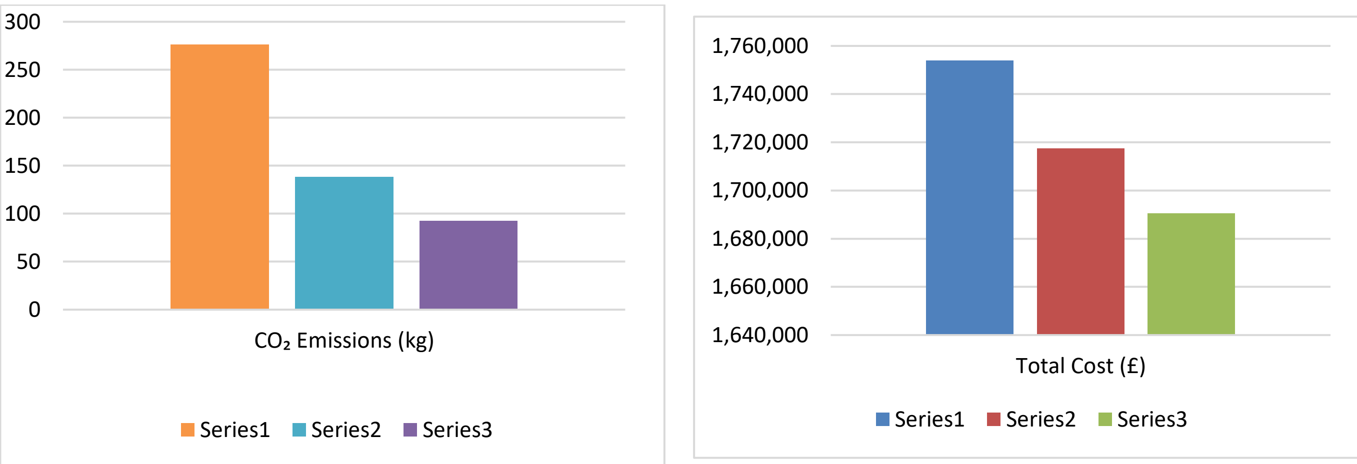

Fig.6. Total operation cost and CO_2 in 3 scenarios

Table 2. Results for all scenarios studied in this paper

Scenario	GFPP Revenue (£)	Total Cost (£)	CO_2 Emissions (kg)	Average Linepack (kcm)
1	1,211,472	1,753,817	276.48	7800
2	1,242,081	1,717,469	138.24	8150
3	1,264,800	1,690,396	92.16	8300

As it is clear, scenario 1 incurs the highest cost due to full reliance on both GDCs and EDCs without considering economic dispatch. Scenario 2 reduces the cost by switching between EDC and GDC units according to electricity and gas prices, achieving a cost saving of about 2.07% compared to Scenario 1. Scenario 3 achieves the lowest cost by leveraging linepack as an operational buffer , which allows for more strategic compressor activation and better alignment with market signals .

These results highlight the importance of price-responsive compressor operation and intelligent linepack management in minimizing system costs.

By reducing the number of operating hours of GDCs, Scenarios 2 and 3 significantly lower carbon emissions. In particular, Scenario 3 shows a 66% reduction in CO_2 emissions compared to Scenario 1, proving the environmental benefits of intelligent scheduling and linepack utilization. Linepack management enables strategic deferral of compression , thereby increasing operational flexibility and reducing dependency on GDCs. Hybrid compressor fleets (GDC + EDC) also allow for fuel switching , optimizing system operation in response to energy market conditions.Two important benefits of proposed method are as follows:

- Enables temporal load shifting of compressors to off-peak hours.
- Increases system resilience by utilizing pipeline gas storage.

5. Conclusion

This study presented a comprehensive optimization framework for the coordinated operation of IGEN, with a focus on leveraging compressor units and linepack dynamics to enhance system flexibility. The proposed MILP-based model incorporated detailed representations of compressor stations, including hybrid fleets of EDC and GDC, and was validated using a real-world case study based on the South Wales gas network coupled with the IEEE 24-bus power system.

By allowing flexible switching between EDCs and GDCs based on real-time electricity and gas prices, the results demonstrated that intelligent scheduling of compressor units can lead to significant reductions in operational costs and carbon emissions. The simulation results show that in the proposed design, i.e. by integrating the optimal linepack model into the compressor station model studied in [8], the amount of carbon dioxide produced has increased from 138.24 to 92.16 kg, which is a 33.3% reduction. Also, the total costs have decreased by 1.57%. In fact, it can be said that the integration of the optimal linepack model has had a very significant impact on reducing environmental pollution, but has reduced operating costs by a very small amount. Applying the methodology to a quantitative case study supports the following key insights:

- Intelligent operation of compressor stations can lead to significant cost savings and emission reductions .
- Linepack provides a virtual reservoir for gas storage, enabling temporal shifting of compression tasks and improving system responsiveness.
- Hybrid compressor fleets (GDC + EDC) offer fuel-switching capability , allowing for better alignment with energy market conditions.
- EDCs have the potential to generate additional revenues through frequency regulation and demand response programs.

To expand this work, future studies may consider:

- Uncertainty modeling : Incorporating wind power uncertainty using stochastic or robust optimization techniques.
- Machine learning integration : Using ML algorithms to forecast prices and improve scheduling decisions.
- Market design : Investigating how gas network operators can be compensated for providing flexibility through ancillary service markets .

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6. References

[1] International Renewable Energy Agency. (2019). Global energy transformation: A roadmap to 2050. Available at: https://www.irena.org/publications/2019/Apr/Global-energy-transformation-A-roadmap-to-2050-2019Edition

[2] WindEurope. (2021). Financing and investment trends 2021. Available at: https://windeurope.org/intelligence-platform/product/financing-and-investment-trends-2021/

[3] Mi, J., & Khodayar, M. E. (2019). Operation of natural gas and electricity networks with line pack. Journal of Modern Power Systems and Clean Energy, 7(5), 1056-1070.

[4] Emdadi, K., Gandomkar, M., & Nikoukar, J. (2025). Energy scheduling of renewable integrated system with hydrogen storage in distribution grid including charging and hydrogen stations of eclectic vehicles. Scientific Reports, 15(1), 16347.

[6] Amiri, M. M., Ameli, M. T., Strbac, G., Pudjianto, D., & Ameli, H. (2024). The Role of Flexibility in the Integrated Operation of Low-Carbon Gas and Electricity Systems: A Review. Energies, 17(9), 2187.

[6] Shen, F., Yang, G., Shahidehpour, M., Ju, P., Wang, C., Xu, X., ... & Zhai, S. (2024). Two-stage optimal dispatch of electricity-natural gas networks considering natural gas pipeline leakage and linepack. IEEE Transactions on Smart Grid, 15(4), 3542-3553.

[7] Wang, H., & Li, Z. (2025, March). Linepack Flexibility in Integrated Electricity-Gas Systems: A Comparative Study of Gas Flow Models and Solution Methods. In 2025 5th International Conference on Advances in Electrical, Electronics and Computing Technology (EECT) (pp. 1-6). IEEE.

[8] Zhao, Y., Xu, X., Qadrdan, M., & Wu, J. (2021). Optimal operation of compressor units in gas networks to provide flexibility to power systems. Applied Energy, 290, 116740.

[9] Chen, Q., Zhao, Y., Qadrdan, M., & Jenkins, N. (2022). Optimal operation of compressors in an integrated gas and electricity system—An enhanced MISOCP method. IEEE Access, 10, 131489-131497.

[10] Chen, Q., Zuo, L., Wu, C., Li, Y., Hua, K., Mehrtash, M., & Cao, Y. (2022). Optimization of compressor standby schemes for gas transmission pipeline systems based on gas delivery reliability. Reliability Engineering & System Safety, 221, 108351.

[11] Amiri, M. M., Ameli, M. T., Aghamohammadi, M. R., Bashooki, E., Ameli, H., & Strbac, G. (2025). Corrections to "Day-Ahead Coordination for Flexibility Enhancement in Hydrogen-Based Energy Hubs in Presence of EVs, Storage, and Integrated Demand Response". IEEE Access, 13, 73135-73135.

[12] Jiang, Y., Ren, Z., Dong, Z. Y., Sun, Z., & Terzija, V. (2024). An optimal dispatch method of integrated electricity and gas systems incorporating hydrogen injection flexibility. International Journal of Electrical Power & Energy Systems, 155, 109662.

[13] Chen, L., Yang, D., Cai, J., & Yan, Y. (2024). Robust optimization based coordinated network and source planning of integrated energy systems. International Journal of Electrical Power & Energy Systems, 157, 109864.

[14] Akbari, B., & Sansavini, G. (2024). Robust scheduling of integrated electricity and gas systems: A cost and flexibility assessment. International Journal of Electrical Power & Energy Systems, 160, 110107.

[15] Ahmadi, S., Amiri, M. M., Nazar, M. S., & Ameli, M. T. (2024, December). Day-Ahead Optimal Scheduling for a Energy Hub Operation Considering Markets for Electricity, Heat, Cooling and Gas. In 2024 14th Smart Grid Conference (SGC) (pp. 1-7). IEEE.

[16] Zhang, X., Strbac, G., Teng, F., & Djapic, P. (2018). Economic assessment of alternative heat decarbonisation strategies through coordinated operation with electricity system–UK case study. Applied Energy, 222, 79-91.

[17] Shabazbegian, V., Ameli, H., Ameli, M. T., & Strbac, G. (2020). Stochastic optimization model for coordinated operation of natural gas and electricity networks. Computers & Chemical Engineering, 142, 107060.