

Thermodynamic Performance Assessment of a 60-MW Above-Ground Compressed Air Energy Storage System Integrated with a GT12 Gas Turbine under Real Operating Conditions
<http://www.doi.org/10.62341/istj-vol39-2-kt16>

Received	2026/09/20	تم استلام الورقة العلمية في
Accepted	2026/10/15	تم قبول الورقة العلمية في
Published	2026/10/16	تم نشر الورقة العلمية في

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Abstract

Peak electricity demand presents a continuing challenge to power-system operation in Libya, particularly during periods of high ambient temperature. This study examines a proposed 60-MW above-ground Compressed Air Energy Storage (CAES) system intended to provide short-duration peak-power support for the GT12 gas turbine at the West Tripoli Gas Power Plant. The proposed discharge duration is 15 minutes. The assessment draws on plant operating data collected on June 2–3, 2024, and on a validated thermodynamic model used to evaluate compressor and turbine performance. The analysis considers mass-flow rate, heat input, net power output, and the sizing of the compressed-air storage system. The results demonstrate that the proposed CAES system increases the available peak power from approximately 100 MW to 135 MW by completely offsetting the compressor work. Despite an increase in fuel consumption required to compensate for the lower temperature of the injected stored air, the system achieves a significant enhancement in net electrical power output compared to the baseline. Furthermore, the proposed modular above-ground storage configuration, utilizing an array of thirty 40-bar industrial

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tanks, demonstrates practical feasibility for regions lacking suitable underground geological formations. The study confirms that integrating CAES with existing gas turbine plants represents a practical solution for improving grid reliability and operational flexibility.

Keywords: Compressed Air Energy Storage (CAES), Gas Turbine, GT12, Above-Ground Storage, Thermodynamic Analysis, Peak Load Support.

تقييم الأداء الثرموديناميكي لنظام تخزين الطاقة بالهواء المضغوط فوق
سطح الأرض بقدرة 60 ميغاواط والمتكامل مع توربين غازي من طراز
GT12 تحت ظروف التشغيل الحقيقية

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الملخص

لا يزال الطلب على الكهرباء وقت الذروة يشكل تحديًا مستمرًا لتشغيل منظومة الطاقة في ليبيا، لا سيما خلال فترات ارتفاع درجات الحرارة المحيطة. تبحث هذه الدراسة في مقترح نظام لتخزين الطاقة بالهواء المضغوط فوق سطح الأرض (CAES) بقدرة تصميمية تبلغ 60 ميغاواط، يهدف إلى توفير دعم قصير المدى لطاقة الذروة (بمدة تفريغ تبلغ 15 دقيقة) للتوربين الغازي (GT12) في محطة كهرباء غرب طرابلس الغازية. يستند التقييم إلى بيانات التشغيل الفعلية للمحطة التي جُمعت في الفترة من 2 إلى 3 يونيو 2024، وإلى نموذج ثرموديناميكي لتقييم أداء الضاغط والتوربين. يأخذ التحليل في الاعتبار معدل

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التدفق الكتلي، المدخل الحراري، صافي القدرة الخارجة، وتصميم نظام تخزين الهواء المضغوط. أظهرت النتائج أن نظام (CAES) المقترح يزيد من قدرة الذروة المتاحة من حوالي 100 ميغاواط إلى 135 ميغاواط تقريباً، وذلك من خلال إحلال هواء الخزانات محل عمل الضاغط بالكامل. وعلى الرغم من الزيادة في استهلاك الوقود اللازمة لتعويض انخفاض درجة حرارة الهواء المخزن المحقون، يحقق النظام تحسناً كبيراً في صافي القدرة الكهربائية الخارجة مقارنة بحالة الأساس. وعلاوة على ذلك، يُظهر التكوين المعياري المقترح للتخزين فوق سطح الأرض (باستخدام 30 خزاناً صناعياً بضغط 40 بار) جدوى عملية للمناطق التي تقتصر إلى التكوينات الجيولوجية الجوفية المناسبة. وتؤكد الدراسة أن دمج أنظمة (CAES) مع محطات التوربينات الغازية القائمة يمثل حلاً عملياً لتحسين موثوقية الشبكة والمرونة التشغيلية.

الكلمات المفتاحية: تخزين الطاقة بالهواء المضغوط (CAES)، التوربين الغازي، GT12، التخزين فوق سطح الأرض، التحليل الديناميكي الحراري، دعم القدرة وقت الذروة.

1. Introduction

Reliable electricity supply has become an increasingly important challenge for modern power systems due to growing electricity demand and the rapid expansion of renewable energy resources. In Libya, gas turbine power plants constitute the primary source of electricity generation; however, their operation during peak-demand periods is associated with increased fuel consumption, reduced thermal efficiency, and higher operating costs. Consequently, integrating large-scale energy storage technologies with existing gas turbine plants has emerged as an effective solution for improving operational flexibility, enhancing efficiency, and supporting peak-load management. Among the available technologies, Compressed Air Energy Storage (CAES) has attracted considerable attention because of its large storage capacity, long service life, and suitability for utility-scale applications storage capacity. Previous studies have demonstrated that CAES can improve grid flexibility, facilitate renewable energy integration, and

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enhance peak-load management. Performance improvements have been achieved through advanced thermal management, turbo-expanders, cooling techniques, and multi-stage compression and expansion, resulting in higher system efficiency and operational flexibility [1-5]. Other investigations have focused on the design and sizing of compressed-air storage tanks, highlighting the influence of operating pressure, tank volume, and compressor capacity on storage performance and system reliability [6]. In addition, economic studies have shown that integrating CAES with conventional power systems can improve operational flexibility and increase the economic viability of energy storage through reserve services and energy arbitrage [7]. Despite these advances, existing research has primarily focused on underground storage systems or small-scale CAES applications. Consequently, the thermodynamic performance, storage-tank design, and operational feasibility of large-scale above-ground CAES systems integrated with gas turbines remain insufficiently investigated, particularly under hot and coastal climatic conditions. This limitation is especially relevant in Libya, where suitable underground geological formations for conventional CAES are scarce, making above-ground storage tanks a practical alternative despite the associated thermal and structural challenges. Furthermore, few studies have combined thermodynamic performance evaluation, storage system design, and actual plant operating data within a unified assessment framework. Therefore, this study investigates the integration of a 60-MW above-ground CAES system with the 167.5-MW GT12 gas turbine unit at the West Tripoli Gas Power Plant using actual operating data and a thermodynamic model developed in Engineering Equation Solver (EES). The proposed framework evaluates compressor and turbine performance, thermal efficiency, net power output, and the design characteristics of the above-ground storage system under real operating conditions. The findings provide practical insights into the technical feasibility of above-ground CAES deployment in regions lacking suitable geological storage formations and offer guidance for improving the flexibility and efficiency of existing gas turbine power plants while supporting future renewable energy integration in Libya. The remainder of this paper is organized as follows.

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Section II presents the proposed methodology, including the GT12–CAES configuration, the West Tripoli Gas Power Plant, thermodynamic performance modeling, and the design of the above-ground compressed-air storage system. Section III presents the results and discussion. Finally, Section IV summarizes the main conclusions and outlines future research directions.

2. System Description and Modeling

This section presents the configuration of the proposed GT12–CAES system and the thermodynamic model developed to evaluate its performance under actual operating conditions.

The overall configuration of the proposed integrated system is shown in Figure 1.

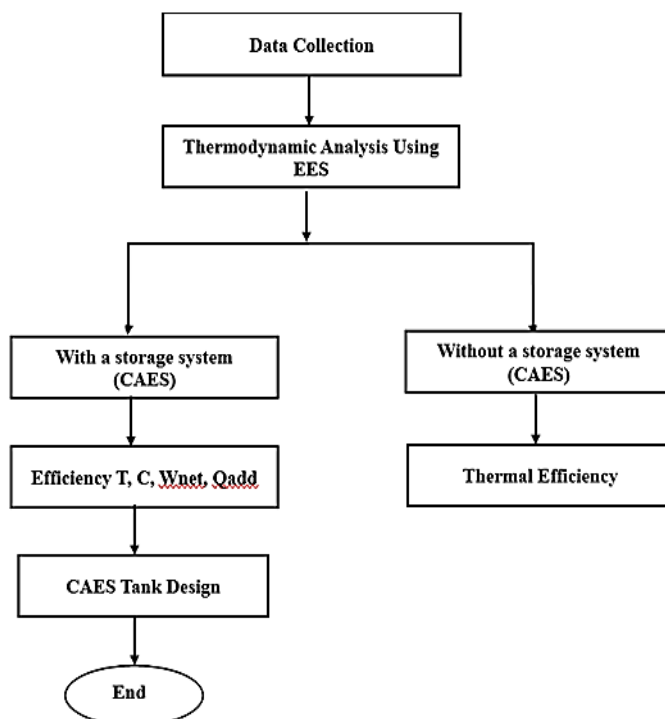


Figure 1. Configuration of the Proposed CAES System

The analysis was performed using measured operating data collected from the GT12 gas turbine at the West Tripoli Gas Power

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Plant during June 2–3, 2024, including compressor and turbine temperatures, pressures, and fuel consumption [8, 9]. Based on these operating data, a thermodynamic model was developed in Engineering Equation Solver (EES) using the first law of thermodynamics, ideal-gas relationships, and component isentropic efficiencies. The developed model was then employed to compare the performance of the conventional GT12 configuration with that of the proposed GT12–CAES system under identical operating conditions.

2.1 System Integration and Model Validation

In the proposed GT12-CAES configuration, the compressed air from the storage tanks is injected directly into the combustion chamber. The nominal CAES system rating is 60 MW, whereas the approximately 35-MW increase represents the estimated additional net electrical output obtained by offsetting the GT12 compressor load under the investigated operating conditions. During peak demand, this high-pressure air completely replaces the air from the main compressor. By offsetting the compressor work (which typically consumes around 35 MW), the turbine can deliver its full gross power output as net power to the grid, increasing the net power output from approximately 100 MW to about 135 MW without exceeding the turbine's design mass flow limits. To ensure the credibility of the EES thermodynamic model, the simulated results were validated against actual measured plant data. The validation showed a high degree of accuracy, with the predicted compressor outlet temperatures and turbine power output matching the measured data with a maximum relative error of less than 3.1%, validating the ideal-gas and isentropic assumptions used in this study.

2.2 Compressor Model

The compressor is one of the most energy-intensive components of the gas turbine, consuming a considerable portion of the turbine-generated power during compression. Therefore, evaluating compressor performance is essential for assessing the effectiveness of the proposed CAES integration. The compressor isentropic

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efficiency and the corresponding isentropic outlet temperature were calculated using (1) and (2), respectively [10, 11]

$$\eta_c = \left(\frac{T_{2s} \cdot c_{p2s} - T_1 \cdot c_{p1}}{T_2 \cdot c_{p2a} - T_1 \cdot c_{p1}} \right) \quad (1)$$

$$T_{2s} = T_1 \times R_p^{(K-1)/K} \quad (2)$$

where η_c is the compressor isentropic efficiency; T_1 is the compressor inlet temperature (K); T_2 is the actual compressor outlet temperature (K); T_{2s} is the isentropic compressor outlet temperature (K); C_{p1} is the specific heat capacity of air at the compressor inlet (kJ/kg·K); C_{p2} is the specific heat capacity of air at the compressor outlet (kJ/kg·K); and γ is the specific heat ratio.

2.3 Combustion Chamber

The combustion process was analyzed using an energy balance relating the fuel and air mass flow rates. The fuel-to-air ratio was calculated using (3) [10-12].

$$\frac{\dot{m}_f}{\dot{m}_a} = \left(\frac{C_{p3} \cdot T_3 - C_{p2a} \cdot T_2}{\eta_{cc}(\text{LHV} + c_{pf}) - C_{p3} \cdot T_3} \right) \quad (3)$$

where $\dot{m}_f$ is the fuel mass flow rate (kg/s); $\dot{m}_a$ is the air mass flow rate (kg/s); LHV is the lower heating value of natural gas (kJ/kg); C_{pg} is the specific heat capacity of fuel at constant pressure (kJ/kg·K); T_3 is the turbine inlet temperature (K); and η_{cc} is the combustion chamber efficiency; C_{p2a} is the specific heat capacity of compressed air at the compressor outlet (kJ/kg·K) and C_{p3} is the specific heat capacity of the combustion gases at the turbine inlet (kJ/kg·K). The combustion process was analyzed using an energy balance between the compressed air and the combustion products. Since the specific heat capacity of the combustion gases varies with temperature, C_{p3} was first determined using (4) [11].

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$$C_{p3} = 1.8083 - 2.3127 * 10^{-3} * T_3 + 4.045 * 10^{-6} * T_3^2 - 1.7363 * 10^{-9} T_3^3 \quad (4)$$

2.4 Turbine Model

The turbine performance was evaluated using the measured inlet and outlet operating conditions. The temperature-dependent specific heat capacity of the combustion gases at the turbine exit was determined using (5) and (6) [10-12].

$$C_{p4s} = 1.8083 - 2.3127 * 10^{-3} * T_{4s} + 4.045 * 10^{-6} * T_{4s}^2 - 1.7363 * 10^{-9} T_{4s}^3 \quad (5)$$

$$C_{p4} = 1.8083 - 2.3127 * 10^{-3} T_4 + 4.045 * 10^{-6} T_4^2 - 1.7363 * 10^{-9} T_4^3 \quad (6)$$

Subsequently, the turbine isentropic efficiency was calculated using (7), while the turbine power output was obtained from the energy balance equation [10-12].

$$\eta_T = \frac{(T_3 * C_{p3}) - (T_4 * C_{p4})}{(T_3 * C_{p3}) - (T_{4s} * C_{p4})} \quad (7)$$

where T_4 and T_{4s} are the actual and ideal exit temperatures, C_{p4} and C_{p4s} are the corresponding specific heat capacities, and T_3 , C_{p3} refer to the turbine inlet state.

2.5 Above-Ground CAES Design

The proposed CAES storage system was designed to offset the compressor load and deliver an additional net power output of approximately 35 MW at an initial operating pressure of 40 bar. Stainless Steel 304 pressure vessels were selected in accordance with ASME pressure vessel design requirements. The storage volume, charging time, and wall thickness were determined using thermodynamic and mechanical design equations. Figure 2 illustrates the proposed storage configuration. [13]

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Figure 2. Above-Ground CAES Tank Configuration

The required electrical energy for the compressed air storage system was calculated based on the target power output and operating duration as follows:

$$E_{\text{req}} = P \times t \quad (8)$$

where P is the required power (W) and t is the operating time (s). Due to system losses, the required energy must be corrected by the overall system efficiency η_{sys} . The input energy is therefore expressed as [14]:

$$E_{\text{in}} = \frac{E_{\text{stored}}}{\eta_{\text{sys}}} \quad (9)$$

where η_{sys} denotes the overall system efficiency and E_{stored} is the useful stored energy. Based on the ideal gas assumption, the required storage volume at the operating pressure is estimated from the total mass of required air (m_{air}) and operating pressure as:

$$V = \frac{m_{\text{air}} \cdot R \cdot T}{P_{\text{op}}} \quad (10)$$

where P_{op} denotes the tank maximum operating pressure, R is the gas constant, and T is the air temperature. For practical considerations related to fabrication, transportation, and maintenance, the total storage volume is distributed among multiple tanks of standard capacity. The number of tanks is determined by [14]-[15]:

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$$N = \frac{V}{V_{\text{tank}}} \quad (11)$$

where V_{tank} represents the volume of a single tank. The charging time is governed by the volumetric flow rate and total storage volume, and is expressed as:

$$T_{\text{charge}} = \frac{V}{Q} \quad (12)$$

where Q is the volumetric flow rate. Accordingly, the pipe diameter required for air transport is obtained from the continuity equation

$$Q = Av \Rightarrow d = \sqrt{\frac{4Q}{\pi v}} \quad (13)$$

where v is the allowable air velocity and d is the pipe diameter. The mechanical design of the tank wall follows cylindrical pressure vessel theory to ensure structural safety under internal pressure. The required wall thickness is calculated according to ASME design practice as:

$$t = \frac{PR}{\sigma_{\text{allow}}E - 0.6P} \quad (14)$$

where P is the internal pressure, R is the internal radius, σ_{allow} is the allowable material stress, and E is the weld efficiency factor. The volumetric flow rate required to achieve a specified charging time is given by:

$$Q = \frac{V_{\text{tank}}}{T_{\text{charge}}} \quad (15)$$

The round-trip efficiency (RTE) was used to evaluate the overall performance of the proposed CAES system and is defined as the ratio of the energy recovered during discharge to the energy consumed during charging [16,17]:

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$$RTE = \frac{E_{dis}}{E_{ch}} \times 100 \quad (16)$$

where E_{dis} is the energy delivered during discharge (kWh); E_{ch} is the energy consumed during charging (kWh); and RTE is Round-trip efficiency (%) [14-17]

3. Results and Discussion

The proposed thermodynamic model was applied to evaluate the performance of the integrated GT12–CAES system under actual operating conditions. The results are presented in terms of compressor performance, combustion chamber characteristics, turbine performance, and overall system performance.

3.1 Compressor Performance

An analysis of the compressor's performance under real-world operating conditions reveals a direct dependency between the pressure ratio and the outlet temperature. As depicted in Figure 3, this temperature rise correspondingly elevates the required compression work during peak-load phases. Consequently, a substantial fraction of the gross turbine output is consumed by the compressor, inherently diminishing the net electrical power delivered to the grid. This operational constraint serves as the primary motivation for integrating the proposed CAES system, which is designed to supply pre-compressed air during high-demand intervals, thereby completely offsetting the compressor's parasitic power consumption. Furthermore, evaluating the correlation between the isentropic outlet temperature (T_{2s}) and the compressor's isentropic efficiency (η_c) across 24 operational measurements indicates that peak efficiency (90%–92%) is localized near the design T_{2s} . Conversely, deviations associated with off-design conditions precipitate a noticeable decline in efficiency. Ultimately, the resultant surge in compression work underscores a fundamental vulnerability of conventional gas turbine operations when subjected to elevated ambient temperatures.

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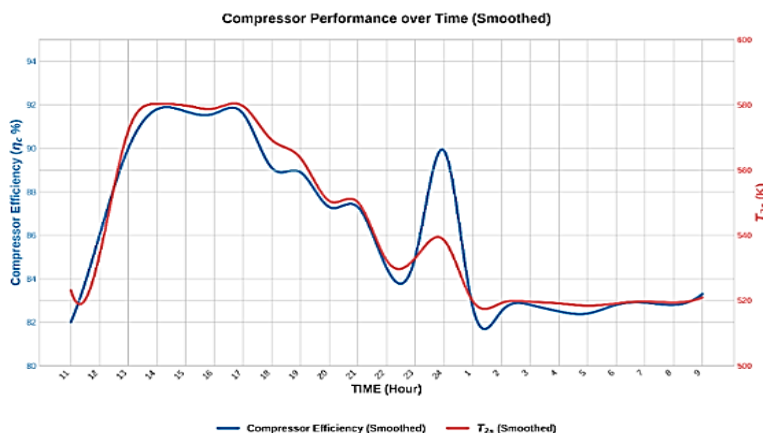


Figure 3. Twenty-Four-Hour Variation of T_{2s} and η_c

3.2 Combustion Chamber Performance

The combustion chamber performance was evaluated based on the variation of the total combustion-gas mass flow rate and the heat input under the actual operating conditions of the GT12 unit. These parameters were analyzed over the 24-h operating period to assess the stability of the combustion process and its response to variations in turbine inlet temperature. The total gas mass flow rate (m_f) remained nearly constant throughout the 24-h operating period, varying marginally from 379.7 to 380.4 kg/s. This stable mass flow rate corresponds realistically to the expected specific work of the 167.5-MW GT12 unit (yielding an acceptable specific work of approx. 355 kJ/kg). Although T_3 increased from 1362.9 K to 1372.2 K, its effect on the total gas mass flow rate was negligible. The hourly mass flow rates of the combustion gas for the GT12 unit are summarized in Table 1, while its relationship with T_3 is shown in Figure 4.

Table 1. Hourly Gas Flow Rate Values for GT12

02/06/2024												
Time	11	12	13	14	15	16	17	18	19	20	21	22
mf (kg/s)	379.9	379.9	379.8	379.8	379.8	379.8	379.8	379.8	379.8	379.8	379.8	379.8
03/06/2024												
Time	01	02	03	04	05	06	07	08	09	10		
mg (kg/s)	379.9	379.9	379.9	379.9	379.9	379.9	379.9	379.9	379.9	379.9		

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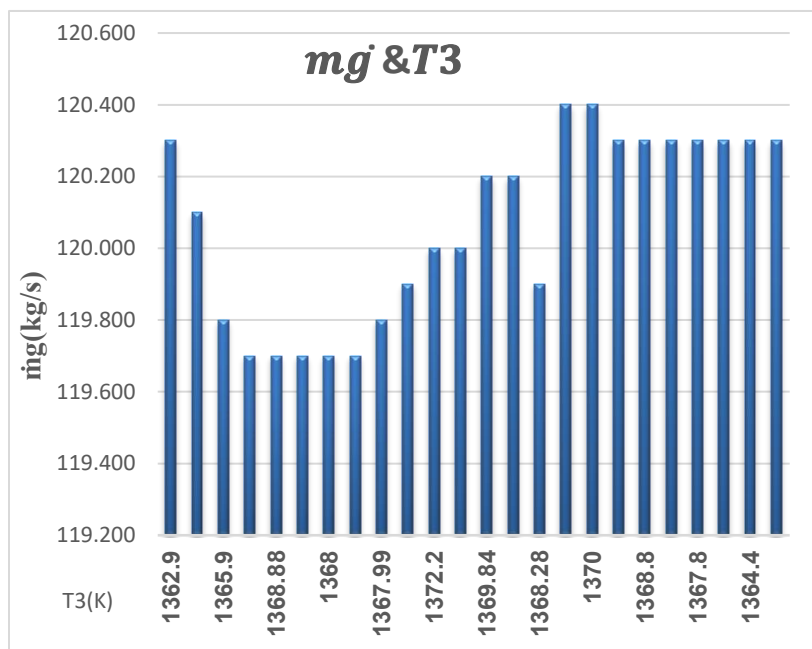


Figure 4. Gas mass flow rate ($\dot{m}_g$) versus (T_3).

The thermal energy added to the system (Q_{in}) was evaluated to quantify the heat input and assess the thermal performance of the GT12 unit using the operating data of Unit 2 at the West Tripoli Gas Power Plant over a 24-h period (June 2–3, 2024). The calculation was based on the gas and air mass flow rates, specific heat capacities, and inlet temperatures. As shown in Figure 5, the relationship between and the turbine inlet temperature T_3 was nonlinear. The heat input decreased initially as increased, reached a minimum near 1370 K, and subsequently increased at higher temperatures. This nonlinear behavior reflects the combined influence of the gas and air mass flow rates, specific heat capacities, and inlet temperatures used in the heat-input calculation.

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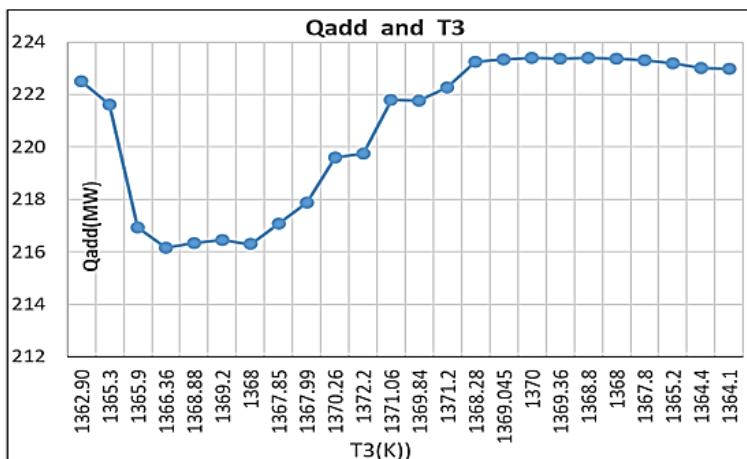


Figure 5. Effect of Q_{in} on T_3

3.3 Turbine Performance

The turbine performance of GT12 Unit 2 was evaluated over the 24-h operating period using measured inlet and outlet temperatures and pressures. The turbine isentropic efficiency was determined by comparing the actual expansion process with the corresponding isentropic expansion, accounting for the thermodynamic irreversibilities associated with the turbine. Table 2 summarizes the calculated turbine isentropic efficiency (η_T) over the 24-h operating period. The corrected efficiency reflects a realistic thermodynamic performance for this class of gas turbines. The efficiency decreased from 88.8% at 11:00 AM to a minimum of 81.6% at 4:00 PM (associated with peak ambient temperatures), followed by a gradual recovery to 86.9% by 11:00 PM. During the early hours of June 3, the efficiency remained relatively stable at approximately 89.3%. Overall, η_T varied between 81.6% and 89.3% during the investigated period. An inverse trend between turbine inlet temperature and turbine efficiency was observed during daytime operation. As the increase in was accompanied by a decrease in η_T . The efficiency subsequently recovered during the evening and early morning, indicating more stable operating conditions. The relationship between T_3 and η_T is shown in Figure 6.

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Table 2. The variation of (η_T) over the 24-hour

02/06/2024													
Time	11	12	13	14	15	16	17	18	19	20	21	22	23
$\eta_T\%$	88.8	88.8	82.6	81.7	81.6	81.6	81.8	81.8	82.5	83.00	84.4	86.7	86.9
03/06/2024													
Time	01	02	03	04	05	06	07	08	09	10			
$\eta_T\%$	89.1	89.3	89.3	89.3	89.3	89.3	89.3	89.3	89.2	89.0			

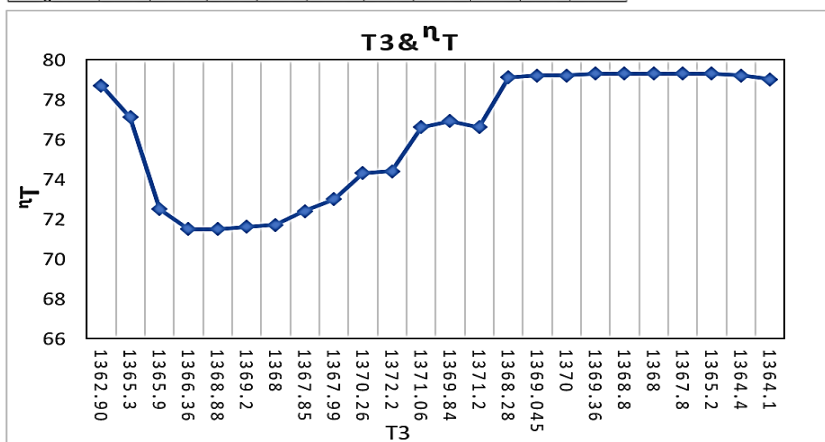


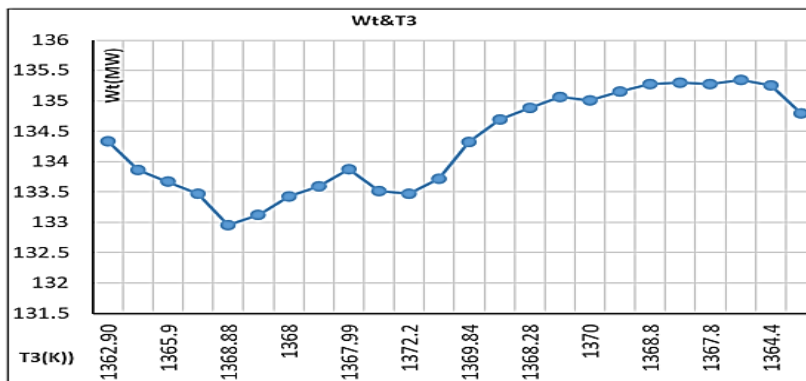
Figure 6. Turbine isentropic efficiency (η_T) versus T_3 .

The turbine power output (W_t) exhibited only minor fluctuations over the 24-h operating period. The hourly turbine power output values are summarized in Table 3. The variation in was associated primarily with changes in gas mass flow rate and turbine inlet and outlet temperatures. The turbine work increased from 132.96 MW to 135.34 MW as varied within the range of 1362.9–1372.2 K, indicating a positive relationship between turbine inlet temperature and turbine power output under the investigated operating conditions. This relationship is illustrated in Figure 7.

Table 3. Hourly variation of turbine power output (W_t)

02/06/2024													
Time	11	12	13	14	15	16	17	18	19	20	21	22	23
W_t (MW)	133.8	137	133.8	133.5	133.1	133.1	133.6	133.6	133.7	133.4	133.2	138.2	134
03/06/2024													
Time	01	02	03	04	05	06	07	08	09	10			
W_t (MW)	134.2	134.5	134.5	134.5	134.6	134.7	134.7	134.8	134.7	134.2			

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The variations in added thermal energy Q_{in} and net work output W_{net} over the 24-h operating period were analyzed to assess the thermal and electrical performance of the GT12 unit. The results show a clear relationship between heat input and power generation. The Q_{in} values exhibited limited variation, initially decreasing from approximately 222.5 kJ to 216.2–216.4 kJ, followed by a gradual increase and stabilization at 223.0–223.4 kJ, indicating effective control of heat input under varying operating conditions. In contrast, W_{net} decreased from approximately 100.3 MW to 93.9–94.4 MW during the initial hours before recovering to about 101.5 MW. As shown in Figure 8, increases in Q_{in} generally correspond to higher W_{net} output, confirming the dependence of electrical output on thermal energy input. The larger fluctuations in W_{net} output also indicate the influence of load variations and component performance.

3.5 Comparative Analysis of System Performance with and without Energy Storage

In order to evaluate energy storage benefits, the conventional GT12 performance (100 MW output) was compared with the proposed GT12-CAES system. Designed to boost peak power, the integrated CAES system successfully increased the net power output to approximately 135 MW by completely offsetting the compressor load. However, because the stored air is injected at ambient temperature (approx. 300 K) compared to the normal compressor discharge temperature (approx. 650 K), the added thermal energy (fuel) must increase to achieve the target turbine inlet temperature. Despite the increased heat input, the significant gain in net electrical power output makes the system viable for peak shaving. These comparative results are summarized in Table 5.

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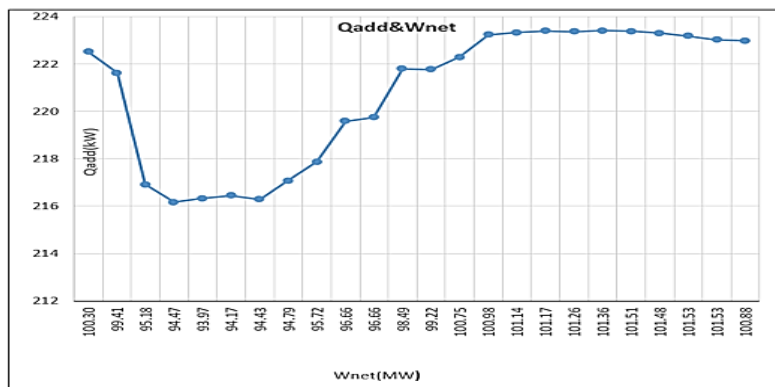


Figure 8. Correlation between Q_{in} and W_{net}

Table 5. GT12 vs. GT12-CAES Performance

Criteria	Before Storage	With CAES Storage
Net Power Output (MW)	~ 100 MW	~ 135 MW
Compressor Efficiency	83% to 92%	(Compressor Off)
Turbine Efficiency	81% to 89%	81% to 89%
Added Heat (MW)	227.27 MW	280.50 MW
Heat Rate (kJ/kWh)	8,155	7,480 (Apparent)

Furthermore, the overall improvement in the net power output (W_{net}) with the integration of the CAES system over the operating period is visually depicted in Figure 9. A proposed above-ground CAES system designed for 15-minute peak shaving requires storing approximately 342,000 kg of air (at a mass flow rate of 380 kg/s). To minimize the spatial footprint, the air is stored at 40 bar, demanding an approximate volume of 7,362 m³ distributed across 30 industrial tanks (250 m³ capacity each). Off-peak charging requires compressing this massive volume of atmospheric air, which takes approximately 20 hours using an upgraded compressor array (240 m³/min). To address the substantial difference between the charging and discharging mass flow rates, the piping system design is bifurcated. The calculated 451 mm pipe diameter is specifically sized for the slow charging phase to maintain a safe air velocity of 25 m/s. Conversely, the discharge pipeline must be designed with a significantly larger diameter, or multiple parallel headers, to accommodate the rapid extraction of 380 kg/s over 15 minutes. A

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comprehensive summary of the design parameters and operational specifications is presented in Table 6.

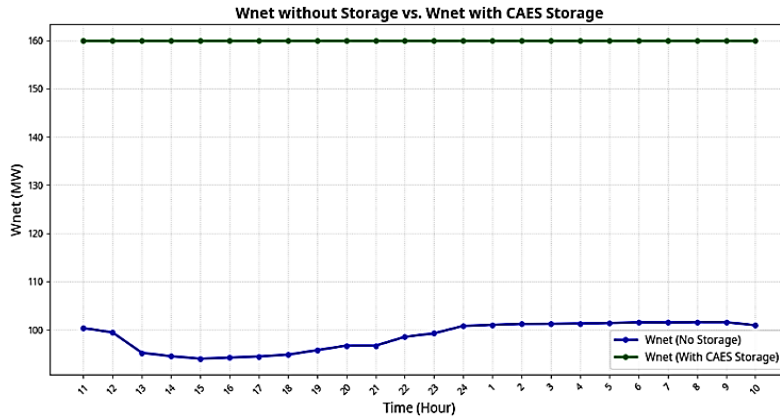


Figure 9. Power output improvement

Table 6. 60 MW CAES System Design Specification

Item	Value	Notes
Target Added Power	~ 35 MW	Offset compressor power
Operation Time	900 s	Equivalent to 15 minutes
Air Mass Flow Rate	380 kg/s	Required for turbine
Operating Pressure	40 Bar	Regulated down before injection
Total Air Volume	7,362 m ³	Volume needed at 40 bar
Volume per Tank	250 m ³	Volume of a single tank
Number of Tanks	30	Required to meet total storage volume
Charging Flow Rate	240 m ³ /min	Measured at ambient conditions
Charging Time	~ 20 Hours	Time to fully charge all tanks
Air Velocity in Pipe	25 m/s	Design-safe flow speed (Charging phase)
Charging Pipe Diameter	451 mm	Sized exclusively for charging flow
Tank Material	Stainless Steel 304	Corrosion-resistant, high durability
Tank Wall Thickness	90 mm	Designed to withstand internal pressure
Weld Efficiency Factor	0.85	Used in thickness calculation
Allowable Material Stress	107.5 MPa	After applying safety factor

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Conclusions

This study evaluated the integration of a proposed 60-MW above-ground compressed air energy storage (CAES) system with the GT12 gas turbine at the West Tripoli Gas Power Plant under actual operating conditions. The proposed CAES configuration successfully increased the available net peak power output from approximately 100 MW to 135 MW by completely offsetting the parasitic compression work during the discharge phase. Although injecting stored air at ambient temperature necessitates an increase in direct fuel consumption, the substantial gain in pure electrical output demonstrates the system's viability. The practical design analysis for a 15-minute short-term peak shaving application indicated a required storage mass of 342,000 kg. At an operating pressure of 40 bar, this requires a storage volume of approximately 7,362 m³, which can be practically provided by 30 industrial tanks (250 m³ each). The charging phase requires about 20 hours using a 240 m³/min compressor array, with a bifurcated piping design ensuring safe velocities during both charging and rapid discharging. Overall, the results demonstrate the potential of modular above-ground CAES integration to enhance the peak power output and operational flexibility of existing GT12 units, especially in regions lacking underground geological formations. Future work should address pilot-scale validation, comprehensive techno-economic assessments, and advanced thermal management (such as recuperators) to further reduce fuel consumption.

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