

Thermodynamic assessment of a hydrogen-fuelled booster for flexible steam cycles: a geothermal case study with alternative integration layouts

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Abstract:

This study investigates a hydrogen-based Booster Mode integrated into a geothermal power plant to provide fast and controllable power enhancement during peak electricity demand. The system exploits stored hydrogen and oxygen, produced in off-peak periods via electrolysis, to feed an oxy-combustion chamber that generates superheated steam for additional power production. In Booster Mode, hydrogen and oxygen are recombined to produce high-temperature steam that expands through a dedicated high-pressure turbine (HPT). The HPT exhaust is then integrated into the existing geothermal steam cycle feeding the low-pressure turbine (LPT), increasing mass flow rate and power output. Two alternative integration layouts are analysed: a Downstream Mixing configuration, where the HPT exhaust is mixed with saturated steam downstream of the geothermal separator, and an Upstream Mixing configuration, where mixing occurs upstream with the flashed geothermal fluid. The two layouts significantly affect steam quality, turbine inlet conditions, and wetness-related losses in the LPT. To accurately capture turbine performance under wet steam conditions, a physics-informed wet steam loss model recently developed through CFD and symbolic regression is implemented. The formulation expresses turbine loss coefficients as functions of wetness fraction and turbine pressure ratio and is integrated into the thermodynamic code to evaluate low-pressure turbine performance under Booster Mode operation. Results highlight how hydrogen-based boosting can significantly enhance power output: depending on the booster operational time, an improvement in LPT power output ranging from 5.3% to 23.26% can be obtained, while accounting for efficiency degradation due to wet steam effects. Although the system is applied here to a geothermal power plant, the proposed hydrogen-based booster is a modular concept that can be generalized to any steam-based power plant requiring fast and dispatchable power enhancement.

Keywords:

Hydrogen; Steam turbine; Energy loss; Wet steam; Thermodynamics.

1. Introduction

The increasing penetration of intermittent renewable energy sources, such as solar and wind, is reshaping modern power systems and intensifying the need for flexible and dispatchable energy solutions [1]. The inherent variability of these resources leads to frequent mismatches between electricity generation and demand, thereby requiring technologies capable of storing excess energy and releasing it during peak demand periods. In this context, enhancing the operational flexibility of existing power plants represents a key strategy to support grid stability while minimizing additional infrastructure investments.

Among the available energy storage options, green hydrogen has emerged as a promising energy carrier due to its flexibility with respect to site topography, to the possibility of medium and long-term storage capacity and the absence of greenhouse gas (GHG) emissions, both during production and use [2]. Power-to-hydrogen-to-power systems enable the conversion of surplus electricity into hydrogen via electrolysis, which can later be reconverted into electricity when required. While several studies have focused on hydrogen utilization in fuel cells or gas/steam turbines [3], [4], these approaches typically rely on dedicated power conversion systems. In contrast, the integration of hydrogen within existing steam power cycles represents a different paradigm, where hydrogen is used to enhance the performance of an already operating thermodynamic system rather than replacing it. However, limited attention has been devoted to this type of integration, particularly as a means of providing rapid and controllable power boosting.

Steam power cycles remain a cornerstone of global electricity generation, including geothermal, biomass, concentrated solar power, and industrial cogeneration systems [5]. These systems are typically designed for steady-state operation and may face limitations in responding to rapid load variations. The integration of thermal energy inputs represents a promising pathway to enhance their flexibility by increasing the steam mass flow rate and the corresponding electrical output. Among hydrogen utilization pathways, thermal conversion via hydrogen–oxygen combustion is particularly suitable for steam-based systems. Unlike electrochemical routes such as fuel cells, which generate electricity directly, hydrogen combustion enables the direct production of high-temperature steam, making it inherently compatible with existing cycle architectures. In addition, hydrogen-oxygen steam generators have demonstrated advantages at MW scale, including high power density, fast load-following capability, compactness, and lower cost relative to electrochemical alternatives [4]. In this context, hydrogen-fuelled oxy-combustion allows the generation of superheated steam that can be integrated into the cycle without introducing non-condensable gases, potentially improving turbine inlet conditions and reducing moisture content in the low-pressure turbine.

Recent work by Manfredi et al. [6] has explored this concept in the context of geothermal systems, demonstrating the feasibility of hydrogen-based integration for flexible power generation. In that study, a hybrid plant layout was developed and optimised, and its thermodynamic and economic performance was assessed under different operating modes. Two alternative solutions for peak-load energy production were investigated: hydrogen based oxy-combustion, where stored hydrogen and oxygen generate additional steam to power the turbines, and a Proton Exchange Membrane Fuel Cell (PEMFC) for direct electrical generation. The results identified the oxy-combustion configuration as the most favourable from an economic perspective, thus motivating further investigation into its integration within steam cycles.

Despite this potential, the integration of hydrogen-based boosting systems into existing steam cycles raises several technical challenges that still need to be investigated, particularly in relation to turbine performance. The introduction of additional steam flows modifies turbine inlet conditions, potentially affecting efficiency, expansion behaviour, and moisture content, especially in low-pressure turbines [7]. Wet steam conditions are known to significantly impact turbine performance due to aerodynamic losses and droplet-related phenomena. Traditionally, these effects have been estimated using simplified approaches, such as the Baumann rule [8], which relies on constant empirical coefficients and may not accurately capture off-design operating conditions.

Recent advancements in computational fluid dynamics (CFD) and data-driven techniques have enabled the development of more accurate models for wet steam losses in steam turbines. Ansari et al. [9] proposed a physics-informed formulation derived from extensive CFD simulations and symbolic regression, expressing loss coefficients as functions of key operating parameters, such as wetness fraction and pressure ratio. These models provide improved predictive capabilities and are suitable for integration into one-dimensional thermodynamic simulation tools.

However, to the authors' knowledge, no studies have systematically investigated the application of hydrogen-based boosting systems in steam power cycles while simultaneously accounting for the impact of alternative integration layouts and advanced wet steam loss modelling on turbine performance. In particular, the interaction between booster-generated steam and the existing cycle configuration, as well as its influence on low-pressure turbine operation under off-design conditions, remains largely unexplored.

This work provides a unified assessment of hydrogen-based boosting in steam power cycles by simultaneously analysing alternative integration layouts and incorporating a physics-informed wet steam loss model to accurately capture turbine performance under off-design conditions. A hydrogen-based booster mode is therefore proposed and analysed using a geothermal power plant (GPP) as a representative case study (based on [6]). The system employs hydrogen and oxygen produced during off-peak periods to generate superheated steam via oxy-combustion, which is expanded in a dedicated high-pressure turbine and subsequently integrated into the existing cycle. Two alternative integration layouts, referred to as Upstream Mixing and Downstream Mixing configurations are investigated to assess their impact on steam quality, turbine inlet conditions, and overall system performance.

A detailed thermodynamic model is developed in Engineering Equation Solver (EES) to simulate the Booster Mode operation. Off-design turbine behaviour is evaluated using Stodola's cone law [10] to relate mass flow rate and pressure drop, while a physics-informed wet steam loss model is implemented to accurately capture efficiency degradation under wet steam conditions. The proposed framework enables a comprehensive comparison between the two configurations, quantifying the trade-off between power enhancement and efficiency losses associated with hydrogen-based boosting.

Although the analysis is conducted on a geothermal system, the proposed approach is not limited to this specific application. The booster concept and modelling framework can be extended to other steam-based power plants, providing a general methodology for integrating hydrogen-based flexibility into conventional thermodynamic cycles.

Table 1. Main operating parameters of the reference GPP and hydrogen-based system.

Subsystem	Parameter	Unit	Value
Accumulation Mode (AM)	H ₂ volumetric flow rate	Nm ³ /h	800
	AWE pressure	bar	30
	AWE temperature	°C	85
	AWE energy consumption	kWh/Nm ³	4.5
	Storage H ₂ pressure	bar	500
	Storage O ₂ pressure	bar	100
	Initial tank pressure	bar	35.2
Booster Mode (BM)	CC pressure	bar	32
	CC temperature	°C	540
Geothermal Power Plant	Resource temperature	°C	325
	Resource pressure	bar	250
	Steam flow	t/h	130
	LPT efficiency	%	78.55
	Non-condensable gases	%	8
	LPT power	MW	22.74

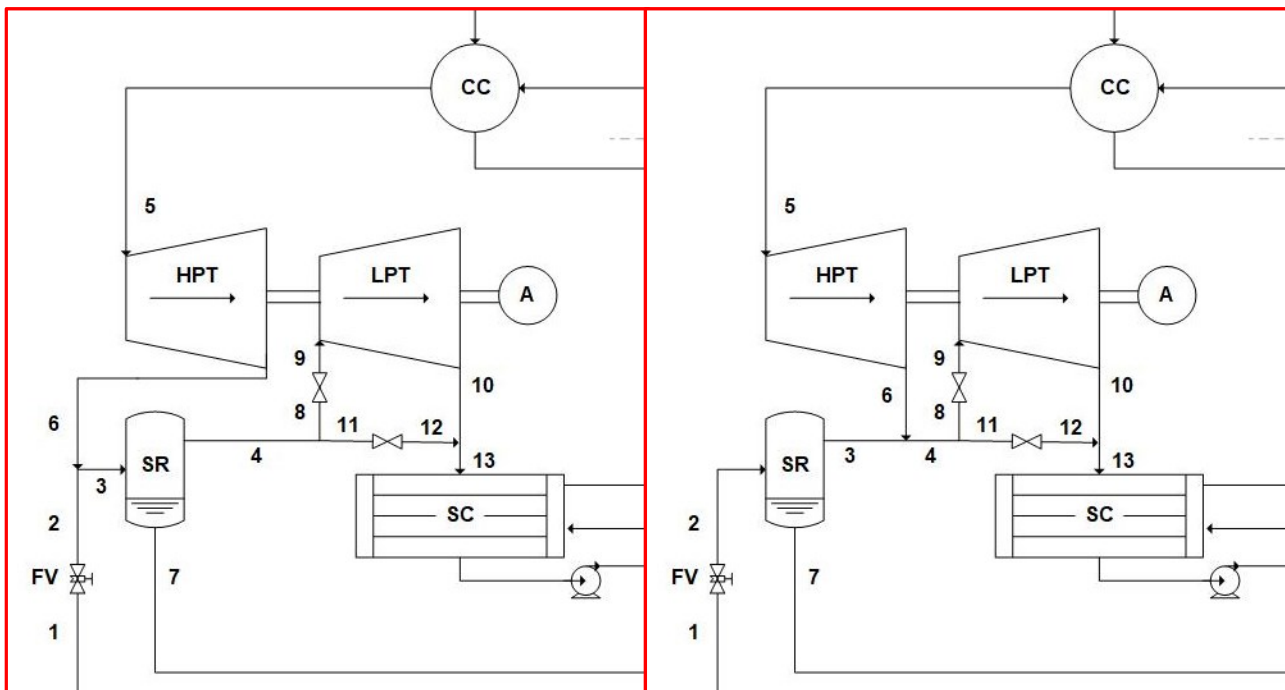


Figure 2. Schematic comparison of the Upstream Mixing (left) and Downstream Mixing (right) configurations for the integration of HPT exhaust within the geothermal steam cycle.

2.2. Off-Design Analysis

By introducing an additional opportunity for energy extraction within a HPT, the booster mode generally proves beneficial for the overall system performance. However, by increasing the mass flow rate at the LPT inlet and modifying its thermodynamic properties as a result of the mixing process, this mode may simultaneously exert detrimental effects on the performance of the latter.

Indeed, the LPT is a pre-existing component and is, therefore, sized for a specific design mass flow rate.

The characteristics of the LPT are influenced by several operational parameters of the booster mode, such as:

- **Combustion chamber pressure** (p_{cc})
- **Booster operating time** (h_b), which sets the discharge rate of the tanks and, subsequently, the mass flow rate entering the geothermal system
- **Separator pressure** (p_{sep})

For the reference GPP, a design mass flow rate of 36.1 kg/s is reported. However, this value may increase up to 40 kg/s depending on the duration of the discharge phase, representing a potential increment of up to +11%. While the literature and operational experience with axial turbines suggest that deviations within $\pm 5\%$ can be accommodated without significant efficiency losses or operational issues [11], variations exceeding this threshold necessitate specific measures to manage the turbine under off-design conditions.

In the present work, the off-design performance of the turbine was evaluated starting from the design conditions using a simplified modelling approach based on Stodola's Cone Law [10]. Assuming that the variations in pressure and critical temperature at the turbine outlet are negligible, the relationship between the pressure drop and the mass flow rate processed by the turbine can be expressed as:

$$\dot{m}_{off} = \Psi_D \cdot \sqrt{\frac{p_{in,off}^2 - p_{out,off}^2}{T_{in,off}}} \quad (1)$$

where the subscripts D and off denote design and off-design conditions, respectively, while in and out refer to the turbine inlet and outlet sections. The Stodola coefficient (Ψ_D) incorporates the thermodynamic and geometric characteristics of the turbine at design conditions. In accordance with [12] the value of this coefficient is assumed to be 16286, while a total of 13 stages has been considered. For both configurations, the outlet pressure was kept constant, while the inlet thermodynamic conditions were uniquely determined through energy and mass balances based on the off-design operational parameters (p_{cc} , h_b , p_{sep}) for both configurations.

To ensure system operation, independently from the adopted configuration, it is fundamental that the turbine is capable of processing the incoming mass flow rate (\dot{m}_4 in Figure 2 **Errore. L'origine riferimento non è stata trovata.**). Consequently, two control logics have been implemented in the code based on the relationship between \dot{m}_4 and \dot{m}_{off} :

- $\dot{m}_4 > \dot{m}_{off}$: A fraction of the flow is diverted through a bypass channel (\dot{m}_{11}), thereby adapting the mass flow rate to the one that the turbine can process with the specified pressure drop:

$$\dot{m}_{off} = \dot{m}_4 - \dot{m}_{11} \quad (2)$$

- $\dot{m}_4 < \dot{m}_{off}$: in this case, the mass flow rate cannot be artificially increased. Consequently, the turbine inlet pressure is reduced via a throttling process, adapting the pressure (p_9) to the one required by the turbine ($p_{in,off}$) to process the desired mass flow rate.

$$\Delta p_{valve} = p_{sep} - p_{in,off} \quad (3)$$

Both control logics are arguably detrimental to the turbine performance: in fact, by considering the turbine power W_{LPT} defined as:

$$W_{LPT} = \dot{m}_9 \eta_{LPT} (h_9 - h_{10}) \quad (4)$$

the first control logic directly reduces the mass flow rate \dot{m}_9 , while the second control logic, by reducing the pressure through an iso-enthalpic lamination, reduces the available enthalpy drop.

2.3. Wet Steam Efficiency

It is important to highlight that alterations in the mass flow rate and in the thermodynamic properties of the fluid do not only necessitate operating the LPT under off-design conditions but also directly impact the turbine efficiency.

Low-pressure turbines represent an extremely critical component in geothermal and, more generally, in steam power plants. This criticality arises from the fact that, since they operate with inlet fluids in saturated or slightly superheated steam conditions, they frequently process two-phase flows [13]. The presence of a significant liquid content (which can reach up to 20% by mass, if no mitigating systems are adopted [14]) can lead to various instabilities, such as erosion or vibrations, resulting in a substantial degradation of turbine performance. In this context, to fully assess the impact of the booster mode on the LPT, it is necessary to analyse its effect on the steam quality and, ultimately, on the turbine efficiency.

In the present work, the turbine has been solved by dividing the total pressure drop over the 13 stages of the expander and assuming a constant pressure ratio along the single stages. For each stage, an isentropic efficiency (η_{is}) of 78.5% [15] has been assumed, while two different formulations of increasing complexity have been adopted to account for the deterioration due to the liquid fraction. Since both of these formulations are expressed as a function of the liquid mass fraction in the stage, that is unknown a priori, an iterative procedure has been implemented and solved for each turbine stage.

2.3.1. Baumann Approach

The Baumann approach represents one of the classical modelling techniques for estimating turbine performance in the two-phase regime, originating from the work of Baumann [8] at the beginning of the 20th century. The fundamental assumption proposed by Baumann involves a 1% reduction in the turbine isentropic efficiency for every 1% increase in the liquid fraction, expressed as:

$$\eta_{wet} = \eta_{is}(1 - \alpha \cdot \beta) \quad (5)$$

Where β represents the liquid mass fraction and α is a unitary coefficient, commonly referred to as the Baumann coefficient. In the current study, the formulation proposed by Kreitmeier [16] is employed, in which a proportionality coefficient of $\alpha=0.6$ is adopted, as it is considered more representative of the operating conditions for medium-to-large scale steam turbines.

2.3.2. Ansari Approach

More recently, the need for formulations capable of accurately accounting for efficiency variations across individual turbine stages has driven the research toward more complex definitions of the Baumann coefficient. Specifically, through a series of CFD simulations on steam turbine stages, Ansari et al. [9] observed that the efficiency reduction is linked not only to the liquid fraction but also to the pressure ratio (PR) of the individual stage. Consequently, a relationship was derived in the form:

$$\alpha = 7.8\beta - 0.46\log(\log(PR)) + \frac{0.041PR}{\beta} - 89\beta^3 - 1.3 \quad (6)$$

This formulation links the Baumann coefficient to the liquid fraction and the pressure ratio (PR) in a strongly non-linear manner, as illustrated in Figure 3. For this reason, it is advisable to operate within the defined validity ranges of the correlation or to exercise caution when performing extrapolations.

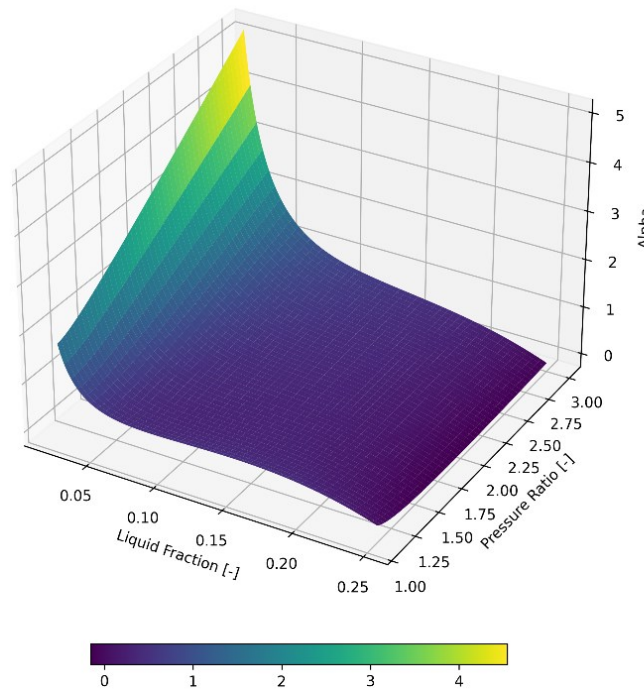


Figure 3. Wet steam coefficient in the formulation proposed by [9].

3. Results

This section initially illustrates the behaviour of the LPT as a function of the off-design parameters, followed by an analysis of the efficiency trends using the previously mentioned approaches for estimating wet steam losses. Finally, the system performance in the two proposed configurations is compared to determine the optimal solution.

3.1. Off-design performance

Given the relatively limited number of independent variables (p_{cc} , h_b , p_{sep}) the off-design analysis was performed by fixing one parameter and monitoring the turbine performance while varying the other two. To

improve the mathematical formulation of the problem, a non-dimensional parameter p_{perc} was introduced, defined as:

$$p_{perc} = \frac{p_{sep} - p_{LPT,out}}{p_{cc} - p_{LPT,out}} \quad (7)$$

This parameter constrains the separator pressure within its physical limits, specifically between the LPT outlet pressure ($p_{LPT,out}$) and the combustion chamber pressure (p_{cc}). To maintain conciseness, the reported results refer exclusively to Upstream Mixing Configuration (UM); however, entirely analogous trends were observed for Downstream Mixing Configuration (DM).

Figure 4 illustrates the isolines of the power generated by the LPT as a function of both the combustion chamber pressure and the separator pressure for a discharge rate of 8 hours.

As can be observed, a curve representing the maximum power output is easily identifiable, corresponding to turbine operation under conditions close to the design point. This curve, which refers to a constant separator pressure, divides the graph into two distinct regions: above the curve, the pressure drop across the turbine is excessive relative to the mass flow rate, necessitating flow throttling; conversely, below the curve, the pressure drop is insufficient for the turbine to process the required flow, thus requiring a bypass of a fraction of the working fluid.

It's interesting to note that the performance degradation observed below the optimal curve is significantly more pronounced than that occurring in the upper region. This underscores that, if design conditions are not reachable, it is always preferable to operate at a separator pressure higher than the identified optimal value.

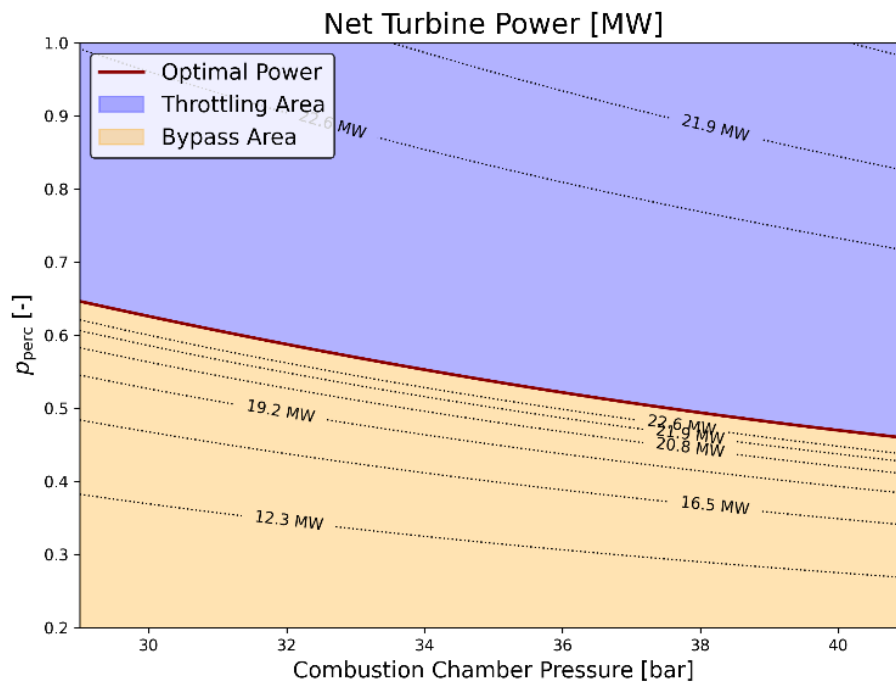


Figure 4. Off-design turbine performance.

In any case, a unique combustion chamber pressure that optimizes the system cannot be clearly identified; conversely, the optimization depends solely on the selection of the separator pressure. This trend is further clarified in Figure 5 **Errore. L'origine riferimento non è stata trovata.**, which compares two analyses conducted with different discharge times.

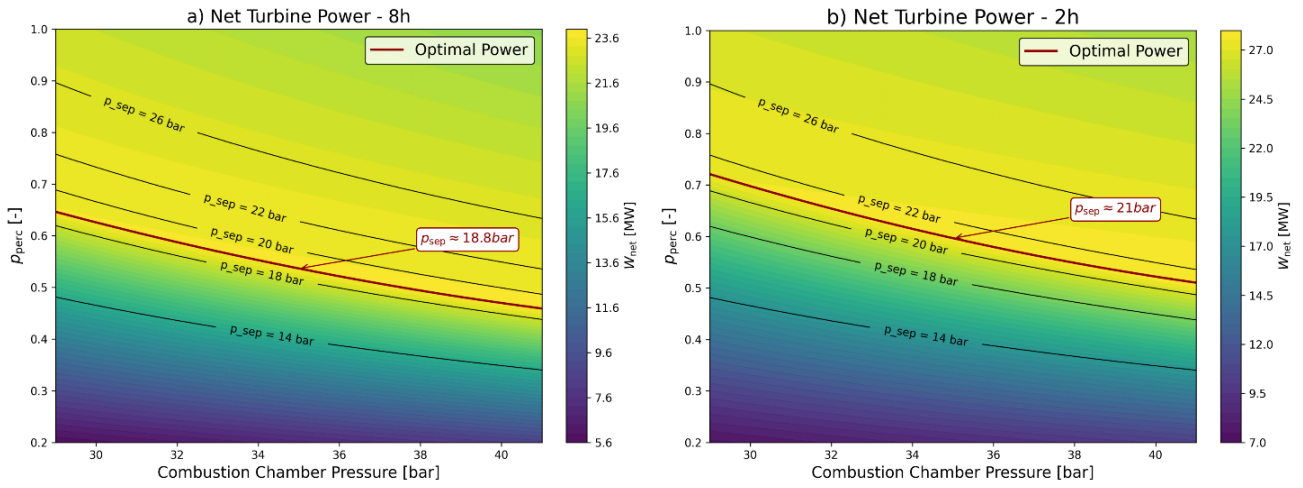


Figure 5. Influence of discharge time on the optimal separator pressure a) Discharge time = 8h b) Discharge time = 2h.

It can be observed that reducing the discharge time, and consequently increasing the mass flow rate, generally results in higher power outputs. However, the qualitative behaviour remains remarkably similar: an optimal separator pressure is consistently present, albeit slightly higher than in the previous case.

Therefore, regarding the operational strategy of the system, it may be advisable to maintain a fixed combustion chamber pressure and adapt the separator pressure based on the scheduled operating hours in booster mode. In scenarios where adjusting this pressure is not feasible, it remains preferable to over-dimension it and reduce the energy content of the fluid via a throttling valve rather than activating the bypass system.

3.2. Wet steam efficiency influence

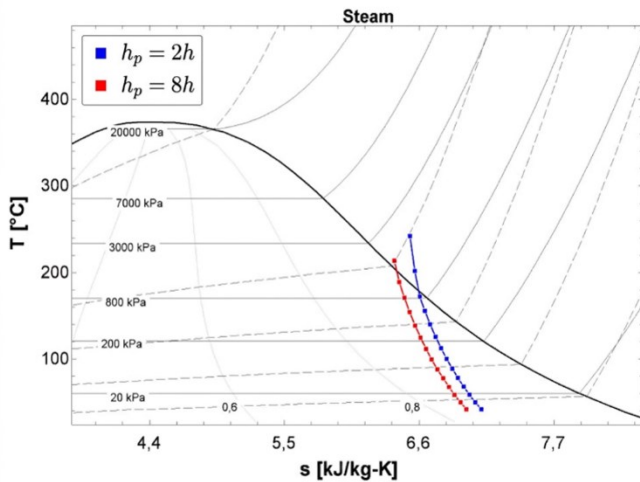
Consistent with the findings presented in the previous section, the analyses regarding the efficiency formulations were conducted by maintaining a constant combustion chamber pressure ($p_{cc} = 32$ bar) and adjusting the separator pressure according to the duration of the booster mode. The results for both UM and DM layout are summarized in Table 2

Table 2. Polytropic turbine efficiency using different wet steam correlations.

h_b [hours]	p_{perc} [-]	p_{sep} [bar]	DM Config.		UM Config.	
			η_{pol} (Baumann) [-]	η_{pol} (Ansari) [-]	η_{pol} (Baumann) [-]	η_{pol} (Ansari) [-]
2h	0.6525	20.9	0.7511	0.754	0.7489	0.7367
4h	0.6121	19.6	0.7452	0.7491	0.7489	0.7374
6h	0.596	19.1	0.7423	0.7493	0.7489	0.7377
8h	0.5879	18.85	0.742	0.7493	0.7489	0.7379

It is interesting to note that the efficiency values in UM layout remain nearly constant, whereas in DM layout, they exhibit an upward trend as the booster mode operating hours decrease. This phenomenon is directly related to the mixing mechanism between the high-temperature flow exiting the HPT and the geothermal fluid. Specifically, in UM configuration, the mixing occurs upstream of the separator. This arrangement ensures that while the saturated steam mass flow rate at the turbine inlet increases due to the energy balance within the tank, its thermodynamic properties remain largely unchanged. Consequently, the steam quality at the turbine outlet remains stable.

In contrast, in DM configuration, the mixing takes place downstream of the separator. In this case, the degree of superheating of the fluid entering the turbine is proportional to the mass flow rate delivered from the combustion chamber. This leads to a significant reduction in the liquid fraction at the turbine outlet, as illustrated in the T-s diagram (Figure 6), and, consequently, to an improvement of the overall efficiency of the turbine.



Turbine Stage	hb=2h		hb=8h	
	β [-]	$\eta_{\text{wet}}(\text{Baum})$ [-]	β [-]	$\eta_{\text{wet}}(\text{Baum})$ [-]
1	0	0.786	0.015	0.778
2	0.009	0.781	0.036	0.768
3	0.030	0.772	0.054	0.760
4	0.047	0.763	0.070	0.753
5	0.063	0.756	0.083	0.746
6	0.077	0.749	0.096	0.740
7	0.089	0.744	0.107	0.735
8	0.101	0.738	0.117	0.730
9	0.111	0.733	0.127	0.726
10	0.121	0.728	0.136	0.721
11	0.131	0.724	0.145	0.717
12	0.140	0.720	0.153	0.713
13	0.148	0.716	0.161	0.710

Figure 6. T-s diagram turbine expansion with different booster mode time and summary table of wet fraction and wet efficiency along the turbine.

A noticeable discrepancy exists between the two efficiency estimation models, appearing more pronounced in UM configuration. While in DM layout this difference averages approximately 0.7% and generally favoring the Ansari formulation, the trend reverses in UM layout. In the latter case, the efficiency calculated via the Baumann approach is roughly 1.6% higher than that predicted by Ansari. This divergence is likely attributable to the distinct mathematical definitions of the coefficients, as illustrated in Figure 7:

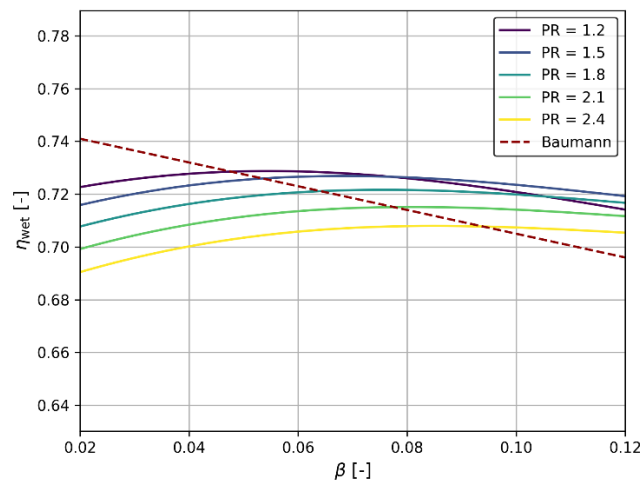


Figure 7. Ansari vs Baumann wet steam coefficient comparison.

Unlike the Baumann model, which exhibits a monotonic decrease, the Ansari formulation significantly penalizes performance at very low liquid fractions; it then reaches a peak before declining again at higher liquid quality. This characteristic is particularly impactful when the penalized stages are the initial ones in the turbine, i.e. those characterized by larger pressure drops under a constant PR assumption. Consequently, UM layout experiences a greater performance penalty. Conversely, this issue is mitigated in DM layout, where the high-pressure stages operate in partially or entirely dry conditions.

3.3. Layout comparison

Finally, Figure 8 illustrates the comparison between the two configurations in terms of the power output extractable from the LPT.

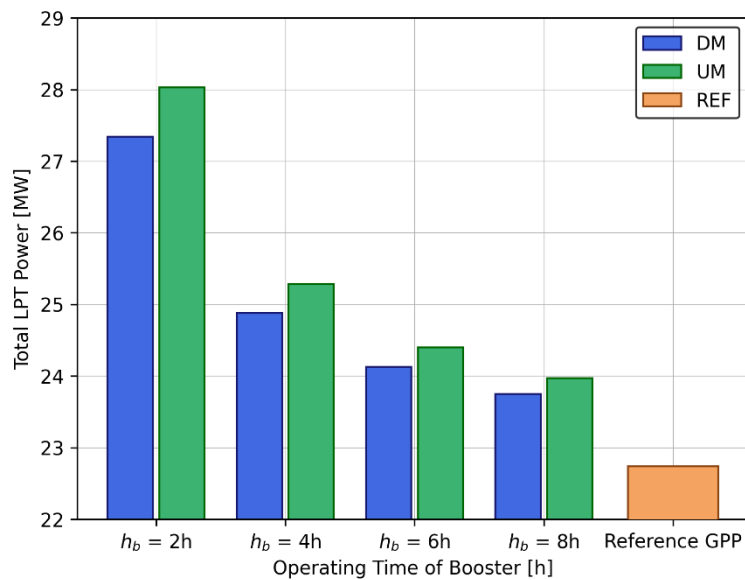


Figure 8. Low pressure turbine power in the proposed configurations.

Building on the findings in the previous section, the LPT efficiency is generally higher in DM configuration than in UM one. However, the power generated by the turbine remains consistently superior in UM layout. This result is probably related to the fact that the inlet mass flow rate, derived from the energy balance within the separator in UM layout, exceeds that achievable through the direct mixing process employed in DM one. Since the turbine power (Eq. (4)) is proportional to both efficiency and mass flow rate, it seems reasonable to assume that the flow rate increment effectively compensates for the efficiency penalty, yielding a higher net power output.

More generally, the booster mode is beneficial for the system not only because of the introduction of an additional power production in the HPT, but also because it improves the low-pressure turbine performance. In fact, as can be noted from Figure 8, the instantaneous LPT power is always higher than the reference GPP value, with an improvement ranging from around 5.3% at $h_b = 8h$ to 23.26% at $h_b = 2h$.

4. Conclusions

This work analysed the integration of an hydrogen-oxygen storage system into an existing geothermal plant, focusing on the influence of the booster operating mode on the performance of the LPT. Two different plant's layouts have been investigated, depending on the location of the mixing between the hot steam coming from the HPT and the geothermal fluid. To properly assess the LPT performance, both a detailed off-design modelling approach and wet steam correlations have been introduced.

The main outcomes can be summarised as follows:

- **Operational guidelines:** the analysis highlights how an off-design control logic based on a throttling device and a bypass channel allows an efficient management of load variation, preserving the operational integrity of the turbine. The results indicate that the system performance are strongly influenced by off-design parameters, such as the separator pressure and the booster mode operational time. On the other hand, the pressure in the combustion chamber plays a marginal role on the LPT performance. As the deterioration is remarkably important using the bypass, an oversizing of the operational separator pressure could be suggested to minimize performance losses.
- **Wet steam efficiency sensitivity:** the comparison between the efficiency formulations from Baumann and Ansari shows that significant discrepancies (averagely of around 1.6%) can be found in the overall turbine efficiency. This could be primarily addressed to the discrepancies in the first turbine stages, where the pressure drops are more relevant.
- **Configuration comparison:** even though DM configuration (mixing after the separator) could lead to a higher turbine efficiency because the inlet turbine fluid is superheated, UM configuration (mixing before the separator) represents the optimal solution in terms of extracted power. In the latter layout, the increase in mass flow rate overcomes the limited turbine efficiency caused by the saturated vapour conditions

Finally, the integration of this storage system proved to be beneficial for improving flexibility and energy production of existing geothermal plants, but ad-hoc control logics have to be adopted to account for the

constraints related to the pre-existing system. Even though the analysis was conducted for a geothermal system, this concept could be easily extended to similar systems, such as steam turbine plants.

Nomenclature

<i>AWE</i>	Alkaline Water Electrolyser
<i>DM</i>	Downstream Mixing
<i>GPP</i>	Geothermal Power Plant
<i>h</i>	booster mode operating time, hours
<i>HPT</i>	High-Pressure Turbine
<i>m</i>	mass flow rate, kg/s
<i>p</i>	pressure, Pa (bar)
<i>PR</i>	pressure ratio, -
<i>UM</i>	Upstream Mixing

Greek symbols

α	Baumann coefficient
β	liquid mass fraction
η	efficiency
Ψ	Stodola coefficient

Subscripts and superscripts

<i>b</i>	booster mode
<i>cc</i>	combustion chamber
<i>D</i>	design operation
<i>in</i>	inlet section
<i>is</i>	iso-entropic
<i>LPT</i>	low pressure turbine
<i>off</i>	off-design operation
<i>out</i>	outlet section
<i>perc</i>	percentage
<i>sep</i>	separator
<i>valve</i>	throttling device
<i>wet</i>	humid

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