

# Flexibilization of Gas Turbine Combined Cycle via Heat Pump: development of control logics via Software-in-the-loop application

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**Abstract.** Flexibilization of Gas Turbine Combined Cycle (GTCC) is a key for plant operations in the present as well as in the near future. The increasing of non-dispatchable sources in the energy production environment causes strong fluctuations in energy price and energy production profiles. The opportunity to enhance flexibility of traditional GTCC is consequently welcomed. This work focuses on integration of a Heat Pump in a GTCC devoted to cogenerative purpose with the goal to integrate energy production, assist the power plant in normal operations and enriches the transient capability of the whole compound. This approach can be developed to be retro-fitted to existing power plant. In particular, a software-in-the-loop (SiL) application is here presented to test the developed control logics governing such power plant. The power plant model is developed and runs under Siemens AMESIM environment, whilst the control system is developed and integrated in Matlab/Simulink environment. The two systems are interfaced and exchange information with the goal to verify reliability of the control logics before going into the real field..

## 1 Introduction

The problem of energy dispatch is coming out strongly where renewables had the opportunity to penetrate and where green sources are going to contribute the most to energy generation in the incoming future. The awaited new explosion of renewables, after the first disruptive penetration at the beginning of '10, will revolution the current energy providing environment. The traditional power plants are going to be shut down in a decarbonisation process which is starting from the coal based cycle, like Italy gave example with phase out of its coal based system by 2025 [1]. The gas turbine, which are going to drive the energy transition towards a renewables based framework, are considered to be however part of the game just in case they will be flexible not only on the side of the load following but also under the fuel viewpoint. In the EU vision, gas turbines are considered to be determinant in providing energy with fuel obtained from power excess indeed, in a power-to-x-to-power framework where a strongly connected environment of energy providers and consumers operate together [2]. As consequence, the perspective for the near future is a strongly connected framework

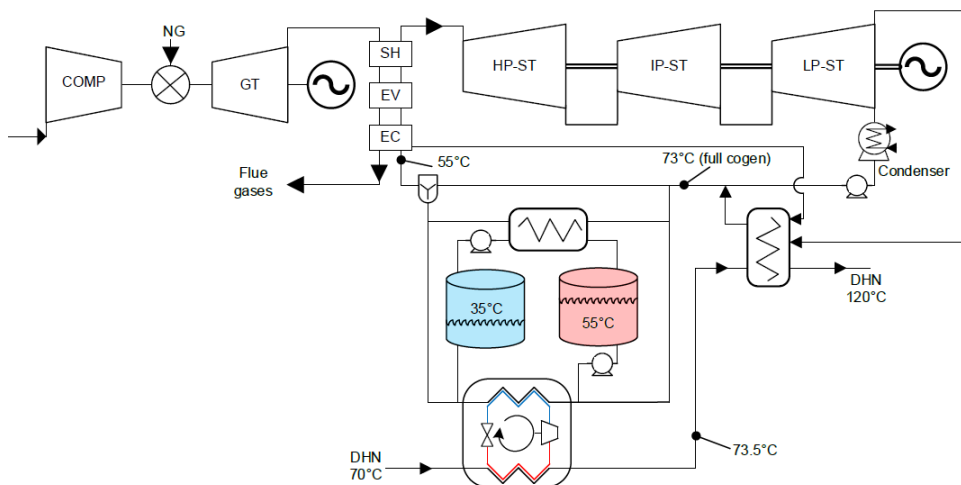
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where a horizontal generation and usage, hierarchically place each player at the same level. Apart from those innovations concerning the market structure [3], the focus is here placed on the gas turbine side. Innovation in power plant flexibility has been carried on at different level – and not only considering the well-known techniques of inlet cooling and inlet fogging. As example it is of interested to mention the super-charged combined cycle presented by Barelli and Ottaviano [4], designed to enhance off-design performance whilst ramps and startups are enhanced via latent heat storage in [5]. This paper faces the control problem of an innovative approach to combined cycle flexibility: the integration of a heat pump and a storage to supply additional heat when required and increase the working map of a combined cycle operating in CHP conditions. This has been presented already in [6]. The adopted control is based on a hierarchical approach, mutated from the smart grid application [7]. Such kind of control systems have found a wide diffusion in the smart grid environment: a review has been recently dedicated to the topic [8] but the application goes from the management of the voltage [8] to the decision-making process in the distribution of energy share [7]. The approach here adopted has been already sketched in [9]. Here the focus is placed on the implementation and the first iterations of the two involved environment: Matlab and Amesim.

## 2 Plant Description

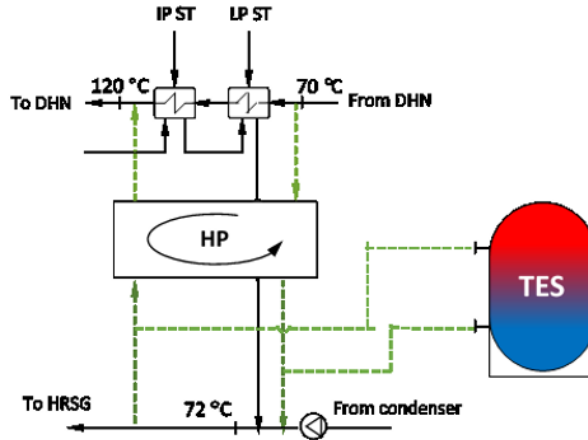
The investigated combined power plant, which integrates a heat pump and a storage in the loop of the combined cycle, is shown in Figure 1. This gives a short description about the system and the flows around the main components. A more detailed sketch is presented in Figure 2 instead. Considering the system layout, the HP is interposed between the condenser discharge and the heat exchangers that feed the DHN. The storage itself is placed between the HP and the condenser discharge line. The storage feeds the HP when the power is requested to be provided to the DHN. The HP can therefore extract energy both from the storage or from the discharge line, dependently on what is the availability of stored energy. Particularly, the usage of the storage is strictly connected to the status of the heat pump.



**Fig. 1.** Power plant layout

The integrated plant, composed by the GTCC, the HP and the storage, works under two different conditions (Table 1): HP ON, corresponding to the usage of the HP to produce thermal energy, and HP OFF, once the HP is switched off. These two operating conditions enclose different set ups. Once the HP is running, the lower temperature sources can varies

from the storage (primary choice) to the condenser discharge line. Once the HP is off, the SOC of the storage drives the operating condition: in case the storage is full, no action is required. In case the storage needs to be fill, this is done by extracting heat from the condenser discharge again. This is done when it is more convenient i.e. when the system load is low.



**Fig. 2.** Detailed sequence of the flows around the HP and the storage

**Table 1.** Operating states of the power plant.

<b>HP ON</b>	
Lower source: Storage or Condenser discharge	
<b>HP OFF</b>	
TES charging with condenser discharge	Normal operation (TES full)

### 3 Control Description

The developed control software has been already presented in the previous paper [9] in its main principles: a framework based on a hierarchic approach was presented. Similarly to [7], the approach is based on considering two principal levels of control:

- A first one which cover a 15 minutes horizon where the decision about the plant configuration must be taken (i.e. HP on/off, storage usage etc)
- A second one, which is constituted by the MPC itself and governs the power plant with real time resolution for plant operations

These two levels operate in real time to govern the global system composed by the GTCC, the HP and the storage. This approach has been chosen as it has been demonstrated to have a perfect fit when different players (e.g. generators, storages etc.) concur to satisfy a unique set of requests. This is the principle of the smart grid operating in islanding conditions: the same approach has been adapted to this system. This time a key player i.e. the GTCC is present and all the adjustments carried out in real time must consider the effect on the GTCC – particularly they must enhance the GTCC and support their operations. The architecture of the MPC used in this work has been presented in [9] and it is derived from [10].

Since the description of the MPC architecture involved is widely available in literature [9-10], the logics of 15 minutes level are indeed unveiled here. This level does not have any direct control on the plant components, but decides the operating point of the whole

compound by taking into consideration the actual status of the power plant, the forecast and the request coming from the grid. This level is in charge to move the system operation from HP ON and HP OFF state and to opt for the best way of using the storage. This level is aware of the energy sold on the day ahead market and which is the prevision for the next steps. Then it uses the original forecast to make some adjustment e.g. on the power set of the HP that can eventually mutate the status of the power plant, such as the turning on/off the HP or to use or not the storage. Particular attention is placed on the storage itself, since the energy availability of the storage must be verified with what has been sold in the next period, particularly in terms of flexibility margin. In case part of this margin has been sold in the next hours by the day-ahead scheduler, these must be taken into account. Considering that the best optimization has been included already on the scheduler, what happen at the 15 minutes level is:

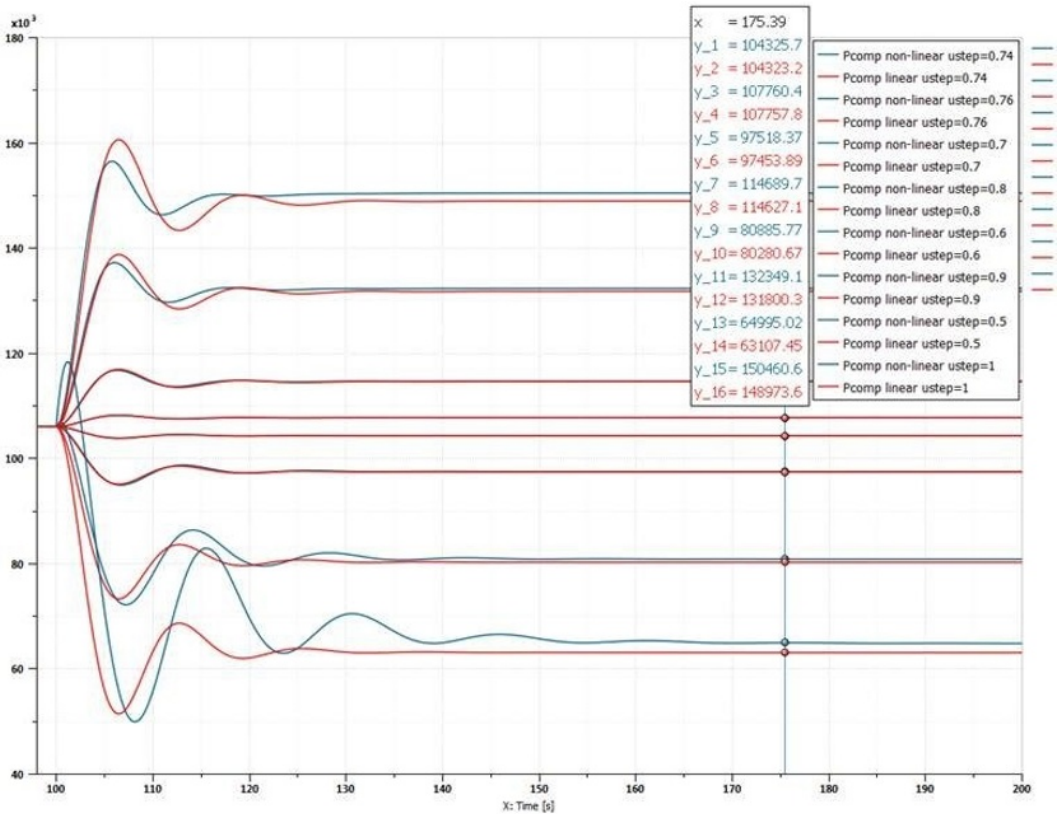
1. Verify if the system is asked for real time grid regulation
2. If yes:
  1. Check the direction of regulation (i.e. power augmentation or reduction):
    1. If Power augmentation
      1. In case the grid operator bought all of the margin -> adopt the solution from the 24h scheduler
      2. In case the grid operator bought part of the margin -> new dispatch based on current status and a mini-forecast optimization focused on storage SOC (e need to look the availability also for the next period)
    2. If Power reduction
      1. In case the grid operator bought all of the margin -> adopt solution from the 24h scheduler
      2. In case the grid operator bought part of the margin -> new dispatch based on current status and a mini-forecast optimization focused on storage SOC (need to look the availability also for the next period)
3. If not:
  1. Verify the system alignment with the original dipatch and correct the system to cover this (basically based on thermal forecast error)
4. Set the status plant (HP ON/OFF and Setpoint)

This sequence is carried out at the beginning of each 15 minutes time windows, and set the operating conditions of the plant to be implemented at the lower level – which architecture is a MPC system. All of the control software has been developed in Matlab/Simulink.

## 4 MPC Embedded Model

The MPC encloses a model of heat pump and storage for the correct management in real time of the process. The model of the storage is a simple integrator, which basically makes an energy balance of the flow coming from and to the storage itself. The interactions with Amesim and Matlab starts here: the model of the heat pump is derived from a detailed model developed in Amesim. Amesim linearized the model around an operative point for being embedded into the MPC – the 75% of the load. This linearized model has one input, which can vary continuously between 0 and 1, and one output, which is the compressor power in Watt. Since the thermal production is meant as an energy recovery, this is not directly controlled, whilst the electric power, which directly affect the total power output of the system, is the actual controlled variable. The linearization carried out in Amesim set the state-space linear model against the complete one. From the equilibrium at  $u=75\%$  several steps to different values were compared. In Figure 3 the linear model response (red lines) with the complete model (blue lines) can be observed. Globally the linearized model shows good

response and the comparison shows a good agreement with the detailed model. Main deviations are evident especially for the lowest step to 50%, but in general the response can be considered aligned with the actual performance of the full-scaled model.



**Fig. 2.** Model comparison between the complete one and the linearized one in Amesim

## 5 Conclusions

This paper introduced the control system developed for management and control of an advanced solution for flexibilization of gas turbine combined cycle via integration of a heat pump in the loop. With respect to previous works, this one describes the 15 minutes horizon function, where decision making process about operating conditions of the power plant is defined. Then, the linearized model implemented into the MPC is presented and compared to performance offered by the complete model developed in Amesim. This will give light to iterations between the control developed in Matlab and the model developed in Amesim and control system will be tested at simulation level before implementation in power plant.

## Nomenclature

CHP	Combined Heat and Power	MEL	Minimum Environmental Load
DHN	District Heating Network	MPC	Model Predictive Control
GTCC	Gas Turbine Combined Cycle	ORC	Organic Rankine Cycle
HP	Heat Pump	SOC	State of Charge
LNG	Liquid Natural Gas	TES	Thermal Energy Storage

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