Gas Turbine Speed Monitoring Using a Generalized Predictive Adaptive Control Algorithm

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Abstract: The outstanding performance of modern gas turbine power plants requires an efficient and robust control strategy in order to recover the losses caused by the undesirable effects and the instabilities related to their operation. Also, these losses can be the cause of their unstable dynamic behaviour during full-load and partial load operation in the unplanned shutdown state. Hence, choosing the right control strategy can improve the operation of this type of machine by increasing its efficiency by up to 60%. This paper proposes the implementation of an innovative control strategy based on a generalized predictive adaptive control algorithm for monitoring the rotation speed of a Solar Titan 130 gas turbine, with the purpose of considering the constraints related to the nonlinear behavior of a turbine during large variations in machine load. The aim is to automatically adjust the parameters of the regulator of the turbine's control loop in real time, with a recursive estimation of these parameters. Using the experimental input/output measurements in order to study its behavior, by integrating the predictive control estimators, ensures the superior performance of the analyzed gas turbine in terms of energy, efficiency and robustness regarding the parametric uncertainties and the variation of the turbine load.

Keywords: Control adaptation algorithm, Generalized predictive adaptive control, Experimental measurements, Linear models, Control robustness and monitoring, Gas turbine, Turbine rotation speed.

1. Introduction

In the gas transportation sector, the task of monitoring a rotating machine is an overly complex activity and requires a large amount of information and reliable operating data for good decision-making in control. This is an essential factor for ensuring the safety of gas supply chain installations in order to make the optimal decisions and take the appropriate corrective actions in their gas delivery processes, from extraction to consumption and to gas distribution and production networks. Nevertheless, the operation of gas turbines triggers environmental issues and constraints in terms of gas emissions, caused by various mismatches in the control laws, which amplify production losses and minimize the technical and economic performance of these gas pipeline installations for the transport of gas over long distances under pressure. In order to solve the problems related to driving gas turbines in gas compression stations and to improve their performance, this paper presents a generalized predictive adaptive control mechanism for the real-time monitoring of a gas turbine, through the adjustment of the regulators of the operating variables of this rotating machine based on automatic techniques. This not only makes it possible to meet the required technical and economic standards, but also to consider the environmental constraints regarding the operation of these gas compression stations and be able to characterize and identify the aspects related to quality production, transformation, and transport of gas.

Indeed, several works have been published and developed in the literature to improve the methods of monitoring and gas turbine systems control. Musa et al. (2021) present the development of a control strategy for the monitoring of health states of gas turbines, using an optimization based on big data for the different operating modes of these machines. This study allows for the analysis of the turbine condition monitoring system and reduces maintenance costs, while also improving the efficiency of the turbine control system under review. Also, Yang et al. (2021) performed a thermodynamic modeling for the development

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of a real-time control strategy applied to a solar micro gas-turbine and Eslami & Banazadeh (2021) improved the control performance for gas turbines in order to reverse performance losses with the selection of minimum control actions, while analyzing the various factors that triggered the aging and degradation of the examined gas turbine, in order to lengthen its useful life. Hence, they have improved the control loop control dynamics limitations optimally, in comparison with the conventional control techniques. Yang et al. (2021) created an optimal fuzzy controller with combined action (proportional, integral and derivative) for the improvement of control quality for a micro gas turbine, with hybridization of the optimized particle swarm optimization algorithms and of a fuzzy regulator rule using an improved Cuckoo search algorithm. The results obtained by this fuzzy adjustment structure show the improvements made to the performance of the analyzed micro gas turbine, in terms of dynamic response, speed and stabilization time as a function of the load variation of this turbine. Also, the fuzzy modeling concept is proposed by Hou et al. (2020a) for modeling and rapid predictive control applied to a gas turbine, with the aim of achieving the stable, efficient and safe operation of the analyzed turbine. Their analysis made it possible to control the disturbance rejection mechanism and ensure the operating stability of the turbine. In addition, several works were dedicated to the improvement of the performance of this type of rotating machine, such as Djeddi et al. (2022), Hadroug et al. (2022) and Choayb et al. (2021). Also, the operating variables of this type of machine were identified by Aissat et al. (2022), Asgari et al. (2013) and Bagua et al. (2021).

This paper aims to propose innovative solutions in order to ensure a good monitoring of gas turbines and to overcome the problems of modeling and regulation of the operating variables of these complex dynamic systems, with the use of an effective and robust control strategy for keeping these machines in good operating conditions and for recovering losses caused by unwanted effects and instabilities related to turbine operation. The aim is to identify and model the dynamics of gas turbines, used in gas compressor stations, by using experimental data, in order to approximate the variables of these nonlinear systems by integrating an advanced control approach in the form of parameter adaptation estimators for control structure parameters. This paper sets forth the implementation of a generalized predictive adaptive control algorithm, for the control of the rotation speed of a Solar Titan 130 gas turbine, installed at the SC3 Gas compression station located in the Wilaya of Djelfa, Algeria, of the gas pipeline GG1 connecting the Hassi R'mel - Bordj Ménail gas fields in Algeria. The purpose is to achieve the efficient operation of this system which relies on the automatic real-time adjustment of the parameters of the examined turbine control loop regulator, to ensure their operational readiness by means of the modern predictive control approach presented in this paper, using experimental measurements of the analyzed turbine inlets / outlets. This is very important for understanding the complexity of gas turbines and for implementing robust dynamic behavior control algorithms, with a view to ensuring the satisfactory monitoring of control actions meant for this type of machines in order to obtain solutions for reducing gas emissions and improving their performance.

This paper is structured as follows. Section 2 presents the modeling of the Solar Titan 130 gas turbine and Section 3 sets forth the proposed generalized predictive adaptive control structure. Section 4 presents the results of the implementation of the proposed approach and the investigations on the Solar Titan 130 gas turbine. Finally, Section 5 includes the conclusions of this paper.

2. Solar Titan 130 Gas Turbine Modeling

To study and formulate the expression of control laws in industrial systems, they must be modeled mathematically beforehand, to set up models of their dynamic behavior. This can be expressed in the form of equations representing the dynamics of the system as close as possible to its actual behavior and constitutes the most important part for the analysis and synthesis of control strategy. Hence, the implementation of control techniques requires the use and development of efficient models for describing the expected behavior of an industrial system, with mechanisms and devices for calculating and designing control laws and controllers. As such, this work sets forth an advanced control strategy based on a generalized predictive adaptive approach, for the regulation of the speed of a gas turbine. The aim is to monitor the driving of this rotating machine, using dynamic models inside the proposed adaptive controller in real time, in order to predict the future behavior of the examined turbine. Hence, these representation models describe the input-output behavior of the Solar Titan 130 gas turbine, based on experimental and identification measurements with a view to their implementation on the regulation system of this turbine.

The examined gas turbine is installed at the SC3 compressor station of the GG1 gas pipeline connecting the Hassi R'mel and Bordj Ménail gas fields in Algeria, which belongs to the oil company Sonatrach and is operated by the branch in charge of gas transport by pipeline (TRC), being located in the village of Moudjebara, in the Wilaya of Djelfa, Algeria. This station has increased the transport capacities of the GG1 42-inch gas pipeline from 7 to 13 billion cubic meters of gas per year, to meet the growing demand for natural gas in the central regions of the country and to supply power generation plants. This compressor station consists mainly of three turbochargers (3x 14.5 MW) equipped with all auxiliary equipment, which are meant to compensate for pressure losses due to the transport of natural gas, so that it could be transported over great distances and has sufficient pressure to be delivered to different users. The SC3 compression station includes three twin-shaft Solar Titan 130 gas turbines, which were designed to provide simple-cycle efficiency at around 36% of power efficiency.

During the operation of the Solar Titan 130 gas turbine the air is sucked into the air inlet of the gas turbine, it is compressed by the multi-stage axial flow compressor and the compressed air is fed into the combustion chamber at a stable rate. The fuel is injected into the pressurized air in the annular combustion chamber. During the gas turbine cranking cycle, this fuel and air mixture is ignited, and continuous combustion is continued as long as there is an adequate flow of pressurized air and fuel. The hot pressurized gas from the combustion chamber expands in the turbine and drives it, while its pressure and temperature drop as the gas exits the turbine. Hence, the gas turbine requires about a quarter of the total amount of air it compresses to completely burn the fuel that comes to it. The excess air is used to cool the combustion chamber and mixes with the combustion products to reduce the temperature of the gas entering the first turbine stage.

With a view to implementing the proposed adaptive control strategy for regulating the speed of a Solar Titan 130 gas turbine and for optimizing its performance through identification tests and validating its implementation for showing its robustness in the context of variations in operational conditions, the following subsection presents the different aero-thermal models used for the control of the Solar Titan 130 gas turbine, with the aim of describing the monitoring problems and the proposed solutions, in order to ensure the robust control of this machine in real time.

2.1 Solar Titan 130 Turbine Models

In the literature on gas turbines, several different models have been presented for the dynamic analysis of gas turbines, such as those of Benrahmoune et al. (2021) and Hadroug et al. (2017). The mathematical model presented in this paper can be defined as an aero-thermal model with a global representation of the components of the gas turbine. This approach was adopted to obtain a high-reliability model for the construction of the turbine state models, with a view to its application for the development of the proposed control strategy. However, the compressor and the turbine are modeled as elements without volume; a plenum capacity is introduced between these elements in order to take into account the unstable mass balance and the burner is modeled as a pure energy accumulator. Other components, such as the turbine cooling module, the air extraction module and the charging module have been determined to complete the turbine model. This model can be applied to simple-cycle or regenerative gas turbines because it includes a mathematical model of the regenerator, these main characteristics are shown in Figure 1, which illustrates the modular scheme adopted for numerical modeling of the Solar Titan 130 gas turbine. Hence, for all components, the algebraic equations are built so that the output values can be obtained from the input variables without iterative calculations. In most cases, input variables are estimated by the incoming stream and, similarly, output variables by the outgoing stream.

For the plenum, the compressor and the turbine are modelled as elements containing no mass (actuator discs), in order to take into account, the volumes of the intake duct, compressor, turbine and diffuser. The plenum is placed at the connection point between these components, inside the plenum the speed variations are negligible, and the pressure and the temperature can be considered constant at each time step.

The outlet pressure and the exhaust temperature are considered to be equal to the pressure and the temperature inside the plenum, respectively, with non-stationary mass equations and the conservation of energy given by:

$$\begin{aligned} V_p \frac{d\rho_2}{dt} &= \dot{m}_1 - \dot{m}_2 \\ V_p \frac{d(\rho_2 e_2)}{dt} &= \dot{m}_1 h_1 - \dot{m}_2 h_2 \end{aligned} \tag{1}$$

where V_p is the plenum volume, ρ is the density, $\dot{m}$ is the mass flow rate, e is the internal energy, h is the enthalpy and $\frac{d}{dt}$ is the derivation function. The density and enthalpy are evaluated based on the pressure and temperature by means of the thermal properties of the gas and the state equation.

In the multi-stage axial flow compressor, the air system of the turbo machine is employed for pressurizing the oil-tight seals and to cool the turbine rotor discs, where the turbine produces compressed air starting when the starter is on which turns the rotor of the turbine compressor. In this dynamic mode, in which the behavior of the compressor is assumed to be almost constant, a simplified approach is adopted to estimate the variation in the air mass flow rate produced by the Inlet Guide Vanes (IGV), which is given by:

$$\dot{m}_a(r_{VIGV}, \omega, \beta) = \dot{m}_a(1, \omega, \beta) r_{VIGV} \tag{2}$$

where ω is the rotational speed, β is the pressure ratio, r_{VIGV} is the ratio of the effective air mass flow to air mass flow at the same rotational speed and at the same pressure ratio. The r_{VIGV} guarantees the opening ratio of the IGVs, completely open to ($r_{VIGV} = 1$).

The linear model for the gas turbine state under consideration is generated from the nonlinear model for the thermodynamic representation of the turbine, where the matrix $F(s)$ of transfer functions closely approximates the behavior of nonlinear turbine system, in the point of full-load operation which is expressed as follows:

$$F(s) = \begin{bmatrix} \frac{\delta\omega(s)}{\delta\dot{m}_f(s)} & \frac{\delta\omega(s)}{\delta r_{VIGV}(s)} \\ \frac{\delta T_0(s)}{\delta\dot{m}_f(s)} & \frac{\delta T_0(s)}{\delta r_{VIGV}(s)} \end{bmatrix} \tag{3}$$

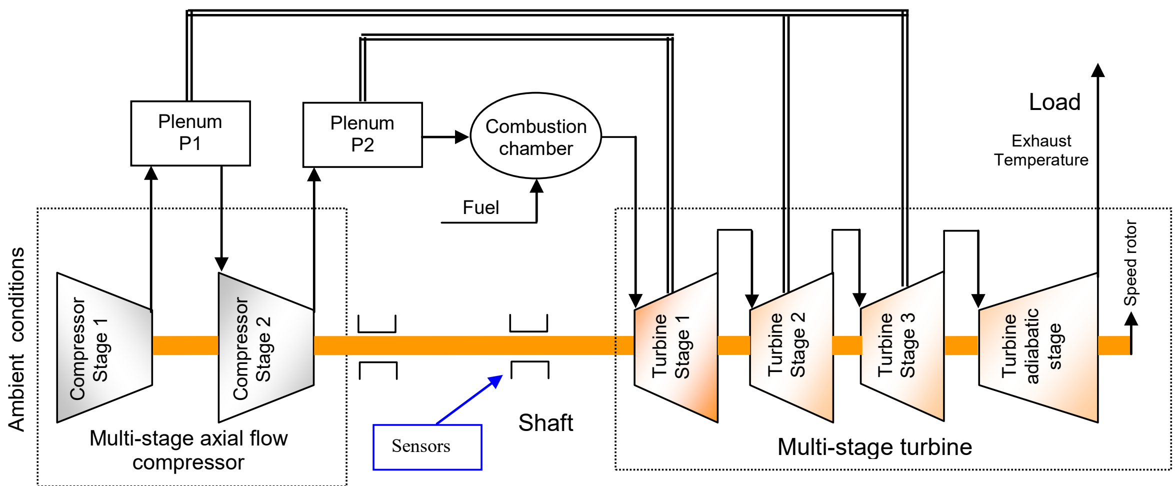

Figure 1. Modular diagram adopted for the numerical modeling of the Solar Titan 130 gas turbine

$$F(s) = \begin{bmatrix} \frac{50}{s} & -\frac{25304}{s+60} \\ \frac{19390}{s+60} & \frac{-114.2s+1860}{s^2+60s} \end{bmatrix} \quad (4)$$

where δ is the deviation from the value at the selected steady-state operating point, $\dot{m}_f$ is the mass flow rate of fuel, f is the fuel and T_0 is the turbine outlet temperature.

The schematic representation of the adaptive control algorithm proposed in this paper is shown in Figure 2, its aim being to control the rotation speed ω of the turbine shaft and the variation in turbine outlet temperature T_0. Hence, the variation of the rotation speed must be controlled because the shaft is directly coupled to the centrifugal compressor and the outlet temperature of the turbine is controlled so as to maintain as much as possible the overall efficiency of the installation under partial load conditions. In addition, the inlet guide vanes of the axial flow compressor can be partially closed, to reduce air mass flow rate and power output, while keeping cycle efficiency constant.

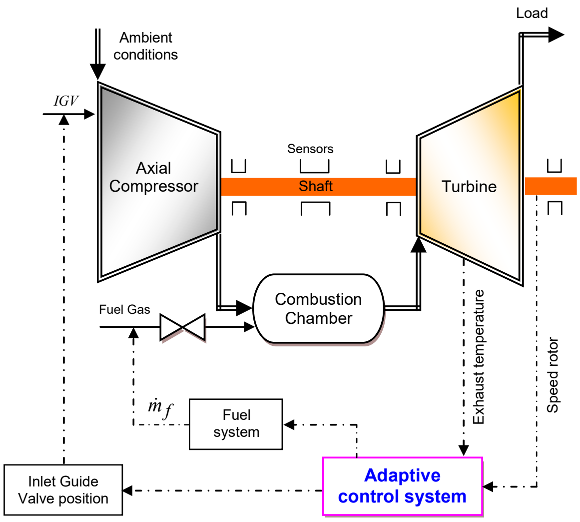

Figure 2. Schematic representation of the adaptive control system applied to the Solar Titan 130 gas turbine

3. Generalized Predictive Adaptive Control Structure

This section sets forth the implementation of the generalized predictive adaptive control algorithm, which is employed in order to predict the behavior of the turbine system and make the best decision regarding its monitoring system, while respecting the constraints related to the different dynamic phenomena affecting the examined turbine. In this advanced approach, control is used to make the system dynamics follow the reference model, using a state representation of turbine variables. This was also tested by Bai et al. (2021), Hou et al. (2020b) and Balamurugan et al. (2016). This approach was also chosen for the technical qualities, such as response rate, accuracy and reliability and its performance and for its ease of implementation for the examined turbine monitoring. Moreover, this approach makes it possible to linearize the closed-loop system, without making complex approximations, around the operating points by a series of transformations, for the analyzed turbine case the input and output turbine operating data was examined. Figure 3 shows the block diagram of the proposed predictive adaptive control model for the gas turbine speed monitoring, so as to analyze and construct with great care the structure of this control model, based on turbine state models using the measurements made on this machine in real time.

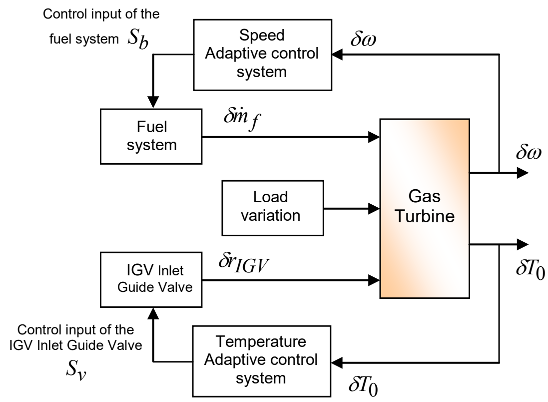

Figure 3. Block diagram of the proposed generalized predictive adaptive control model

In this section the predictive control is developed to control the anticipatory effects with respect to a reference trajectory to follow, based on the prediction of the future behavior of the turbine system by minimizing the deviation of these predictions from the reference trajectory in the sense of a cost criterion, while respecting the constraints and operating modes of the examined turbine. Indeed, after the acquisition of input / output turbine operating data and its filtering and normalization processing, a parametric model adaptation for this rotating machine is made using an adaptive algorithm. This makes it possible to apply the generalized adaptive control method in a direct way for the control of the turbine rotation speed, this mechanism is illustrated in Figure 4. The experimental validation and the results obtained by these control laws are presented and discussed in the next section, with the purpose of testing their actual performance in terms of reference trajectory tracking and robustness and for approving their feasibility.

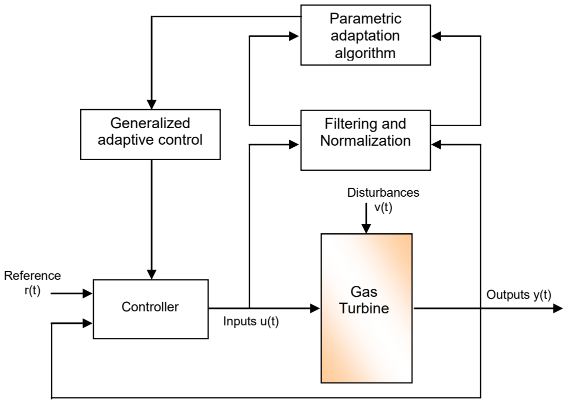

Figure 4. Diagram of the generalized adaptive control method applied to the examined gas turbine

4. Results of the Implementation of the Proposed Approach and Investigations on the Solar Titan 130 Turbine

The modeling of the examined Solar Titan 130 gas turbine is a necessary step for the control of the operating variables of this machine. Considering the structure of the predictive control model presented in the earlier section, the mechanism of turbine regulation can be inferred to achieve this generalized adaptive control. Then, for the turbine speed regulation it is assumed that the displacement of the air inlet guide vanes is in the open position $S_v = 1$, which corresponds to the maximum opening which is assumed to be the condition at the design point, after start-up and charging of the Solar Titan 130 gas turbine.

4.1 Model Parameters Initialization

For this purpose, the generalized predictive adaptive control algorithm makes it possible to generate the control $u(t)$ applied to the turbine variables, for the automatic online adjustment (in real time) of the regulation block after estimation of the parameters of the turbine model and to approach the reference path of the output $y(t)$ which is the turbine speed $\omega(t)$ at the setpoint reference $r(t)$, using the formulation of control laws given by equation (3). Hence, the initialization of the turbine model parameters is obtained as follows:

$$A = \begin{bmatrix} 0.0001226 & 0.007699 & 0.01123 \\ -0.04823 & -3.015 & -9.988 \\ 0.08044 & 16.77 & -27.26 \end{bmatrix};$$

$$B = \begin{bmatrix} 0.0006161 \\ -0.3151 \\ -1.479 \end{bmatrix};$$

$$C = \begin{bmatrix} 9.231e+04 & 33.59 & 5.965 \end{bmatrix}; \; D = 0$$

This allows one to obtain the turbine model as follows:

$$\begin{aligned} &A(q^{-1}) = 1 + a_1 q^{-1} + a_2 q^{-2} \\ &B(q^{-1}) = b_0 + b_1 q^{-1} \\ &n_a = 2; n_b = 1 \end{aligned} \tag{5}$$

where q^{-1} is the lag operator defined by $q^{-1}y(t) = y(t-1)$, n_a is the number of parameters of $A(q^{-1})$ and n_b is the number of parameters of $B(q^{-1})$.

The vector of the initial parameters can be inferred, namely $\theta(0)$, given by: $\theta(0) = [a_1, a_2, b_0, b_1] = [-1.835, 0.835, 0, 0.4563]$, with the initial gain equal to 10, this initial gain measures the difference between the estimated parameter values and their initial values, this gain is chosen to be low so as not to have a big difference between the estimated parameter values and their initial values. One shall consider the gain adaptation function $F(t)$ and the normalization function $\eta(t)$ at $t = 0$, $F(0) = 1$ and $\eta = 1$, to have a normalization of the turbine input/output signals, with the ponderation function $\mu(t)$ taking the values $\mu(0) = 0.92$ and $\mu_0 = 10$, and the ratio of the forgetting factors $CC = 0.97$ with the sigma window value equal to 0.01 and the value of the normalization filter equal to 0.94.

With these initial conditions, the control law parameters are chosen : $h_p = 4$ to cover the system response, where an increase in h_p may cause poor tracking, $h_i = 1$ must be greater than the turbine control response delay d, with a positive weight sequence $\lambda = 5$ to achieve a good performance of the control strategy, $d = 1$ to obtain a good estimate of turbine model parameters given by $P(q^{-1}) = 1 - 0.8q^{-1}$ for better performance in reference of setpoint pursuit $r(t)$, and considering the stable asymptotic perturbation compensation polynomials $F(q^{-1}) = 1$ and $G(q^{-1}) = 1$.

After initialization of the parameters of generalized predictive adaptive control system applied to the Solar Titan 130 turbine, the obtained results were discussed for two cases: the first case without disturbance effects and the second case with the disturbance effects affecting the turbine system.

4.2 The Obtained Investigation Results

The comparative results for the predictive control without and with disturbance effects for the reference tracking are shown in Figures 5 to 8, for these two case studies, the structure of the control is the same. Regarding the obtained results for the case without disturbance effects, Figure 5 shows the regulation of the rotational speed $\omega(t)$ by input to the reference $r(t)$ and Figure 6 shows the variation of the rotational speed $\omega(t)$ control applied to the Solar Titan 130 turbine. And in the case of the turbine rotation speed control with disturbance effects, Figure 7 shows the variation of the turbine rotation speed $\omega(t)$ in the presence of the disturbance effects by input to the reference $r(t)$ and Figure 8 shows the control $u(t)$ applied over the time interval from 0 to 450 min.

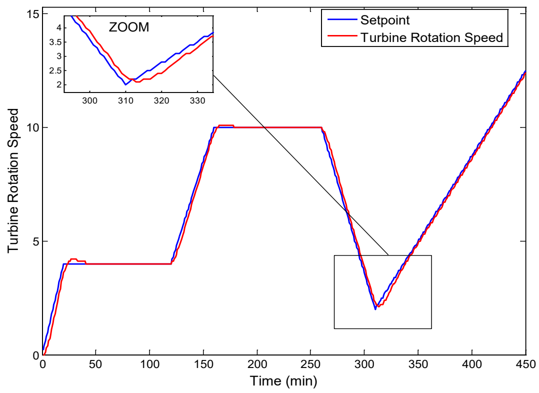

Figure 5. Regulation of the rotation speed $\omega(t)$ by input to the reference $r(t)$ without effect of disturbances

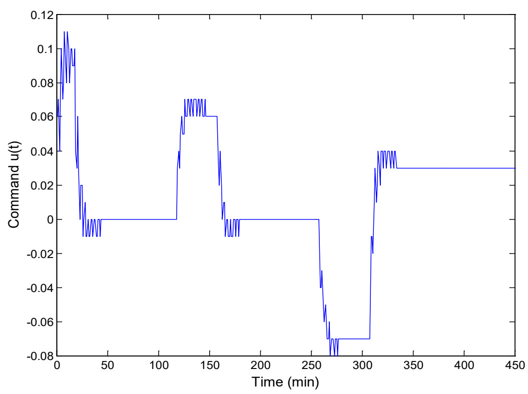

Figure 6. Variation of the control $u(t)$ without the effect of disturbances

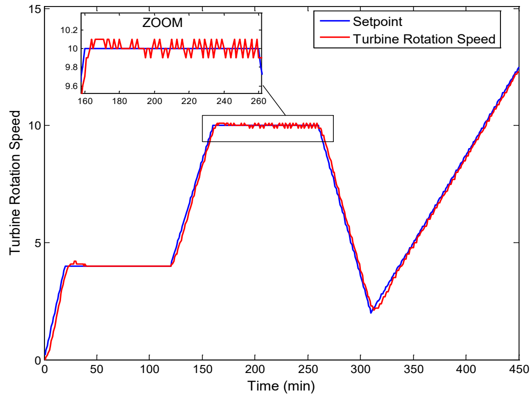

Figure 7. Regulation of the rotation speed $\omega(t)$ by input to the reference $r(t)$ following the effect of disturbances

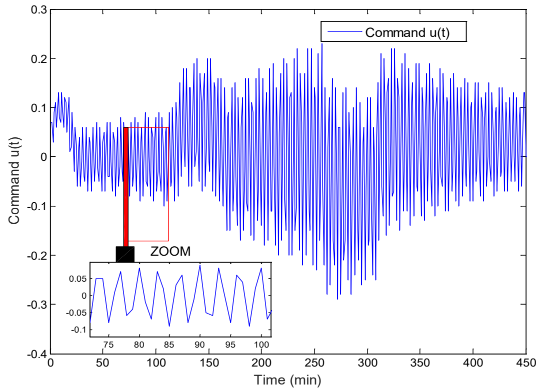

Figure 8. Variation of the control $u(t)$ following the effect of disturbances

Adaptive control is used for calculating and adjusting the controller parameters and for providing reference model tracking in the presence of disturbances. Also, based on the obtained results, it can be seen that the output perfectly follows the reference in tracking and in regulation with acceptable tolerance overshoot of 05%.

The development of a predictive control law applied to the control of turbine rotation speed requires considering constraints on the input and output of turbine operation, depending on the parameters of the regulator and the obtained model, in order to adjust these parameters directly from the real-time regulator for the turbine rotation speed control. In fact, the regulator parameters remain unchanged, after introducing the effects of external disturbances on the turbine system, with the application of the control and the continuation of the reference trajectory is ensured, by using the values of the parameters of this regulator (a_1 , a_2 , b_0 and b_1). Hence, Figures 9, 10, 11 and 12 show the variations of these parameters. Similarly, if the rejection of disturbance effects is done quickly, it results in variations of the estimated parameters and in the observed oscillations on the turbine rotation speed control.

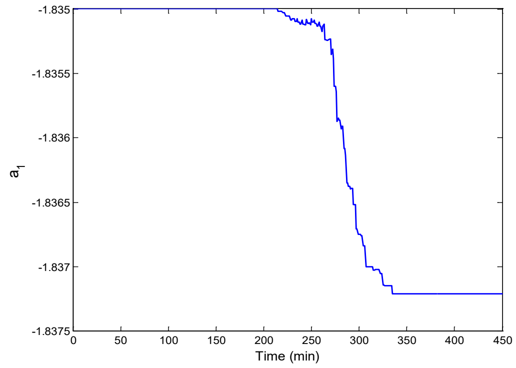

Figure 9. Variation of the parameter a_1 following the effect of disturbances

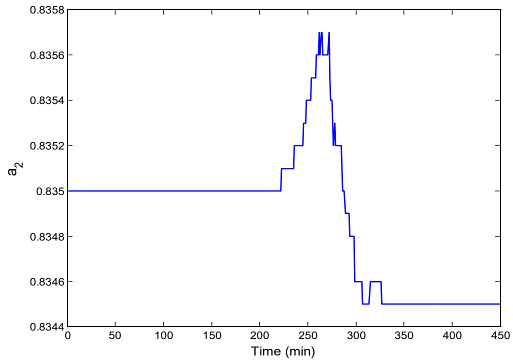

Figure 10. Variation of the parameter a_2 following the effect of disturbances

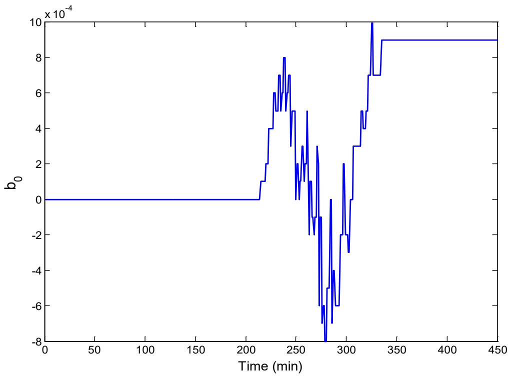

Figure 11. Variation of the parameter b_0 following the effect of disturbances

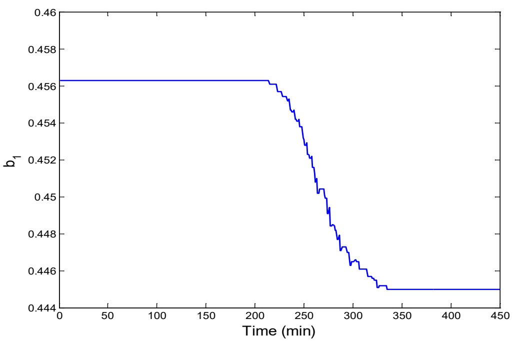

Figure 12. Variation of the parameter b_1 following the effect of disturbances

4.3 Control Robustness Applied to the Solar Titan 130 Turbine

In order to examine the robustness of the generalized predictive adaptive control applied to the gas turbine model, the initial vector $\theta(0)$ of parameters is set 50% away from the initial parameters of the system, with $\theta(0)=[0.9175, 0.4175, -0.05, 0.22815]$. This control is optimal and stable in the closed-loop system. This robustness is ensured by the parametric variations for regulators as a function of the reference $r(t)$. This is tested through the change of the initial output vector $\theta(0)$ and relative to the dynamics of zeros around its equilibrium point. Figure 13 shows the regulation of the rotation speed $\omega(t)$ by input to the reference $r(t)$ and Figure 14 shows the variation of the rotational speed control applied to the turbine, following the change of the initial vector θ.

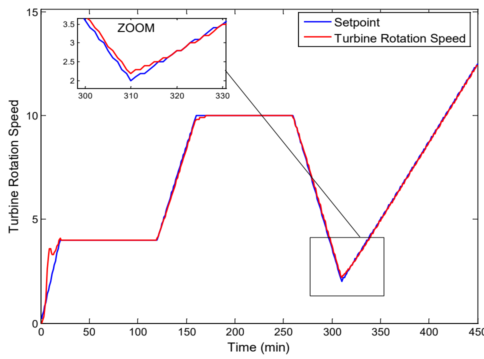

Figure 13. Regulation of the rotation speed $\omega(t)$ by input to the reference $r(t)$ as an effect of the change of the initial vector $\theta(0)$

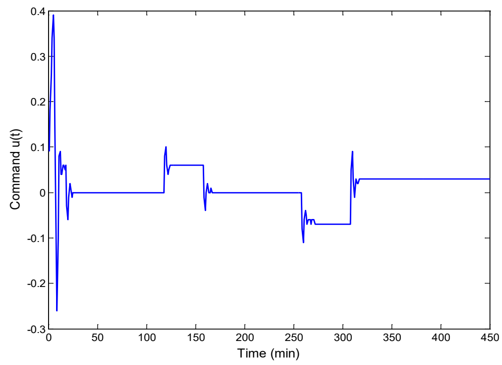

Figure 14. Variation of the control $u(t)$ as an effect of the change of the initial vector $\theta(0)$

The obtained results are illustrated by Figures 15, 16, 17 and 18, which represent the variations of the parameters a_1, a_2, b_0 and b_1 respectively, following the change of the initial vector $\theta(0)$.

The obtained results show how the control algorithm makes the parameters of the system (a_1, a_2, b_0 and b_1) vary rapidly on the first sequence to bring the system back to following the setpoint and the system is heading towards a stable operating point of the turbine, which results in the variation of the observed control on the first sequence.

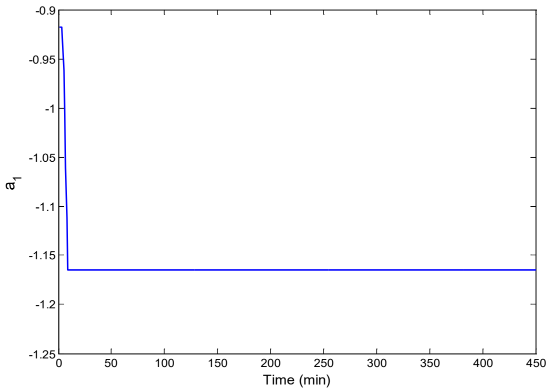

Figure 15. Variation of the parameter a_1 as an effect of the change of the initial vector $\theta(0)$

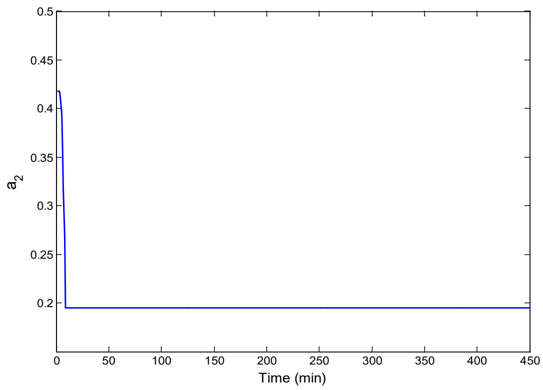

Figure 16. Variation of the parameter a_2 as an effect of the change of the initial vector $\theta(0)$

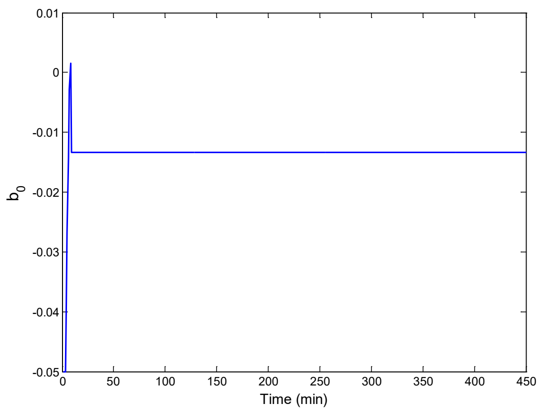

Figure 17. Variation of the parameter b_0 as an effect of the change of the initial vector $\theta(0)$

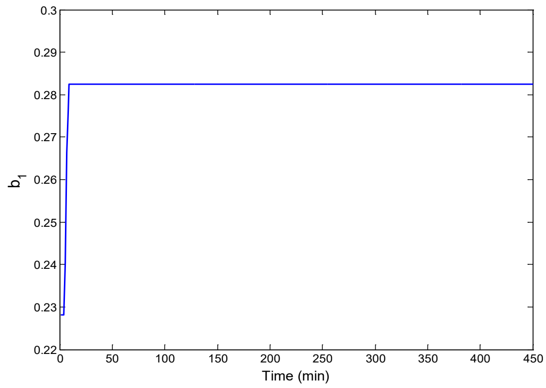

Figure 18. Variation of the parameter b_1 as an effect of the change of the initial vector $\theta(0)$

5. Conclusion

This paper proposed an advanced control strategy based on a generalized predictive adaptive control algorithm, for the monitoring of the operating variables of a Solar Titan 130 gas turbine. This new solution has proven to be innovative and promising for the resolution of conventional control problems of gas turbines, allowing the examined turbine to be operated close to the reference model, in order to increase its efficiency and ensure its operational stability. The novelty of this approach lies in the use of linear models with variable parameters correctly describing the complex dynamics of a turbine in real time, based on experimental measurements and the identification of the input-output behavior of the Solar Titan 130 gas turbine, with an adaptation in real-time control parameters, using a series of recursive estimates, with the purpose of predicting the turbine's behavior. Hence, the proposed generalized predictive adaptive control algorithm allows the adaptation of the predictive regulator of the turbine's control loop in real time and allows the inclusion of the constraints on the operating variables of the turbine which were manipulated during its operation, to ensure the automatic adjustment of the regulator of the turbine's control loop and maintain the desired level of performance with a reliable setpoint tracking, even under the influence of disturbances and operating constraints. In addition, the ease of implementing this predictive control strategy for monitoring the rotation speed of the gas turbine, assuming the displacement of the air inlet guide vanes is in the open position, ensures the robustness of this approach. The obtained results showed that the performance of the proposed control algorithm is better and robust, even for the cases of critical speeds (close to the limit of stability) in the dynamic mode, which gave an error between the reference trajectory and observed behavior which tended to zero. Hence, the generalized predictive adaptive control strategy allows a very satisfactory monitoring of the speed of the imposed turbine rotation trajectory and can be associated with a distributed turbine control system for possible planned control of the temperature of the combustion chamber outlet of this machine.

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