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Optimizing FPSO Oil Processing: An Expert System with Genetic Algorithms for Setpoint Control

Optimización del procesamiento de petróleo en FPSO: Un sistema especializado con algoritmos genéticos para el control del punto de ajuste

Otimizando o Processamento de Óleo em FPSO: Um Sistema Especialista com Algoritmos Genéticos para Controle de Setpoint

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Abstract

Increasing the productivity of an offshore oil production unit is a challenge in environments such as the Brazilian pre-salt. Since controlling the oil treatment process is essential for the continuity of the platform and considering that most current units use conventional feedback control, there was a need to optimize the control system for the separation process, well flow control and ballast tank filling to reduce the number and duration of process shutdowns. This article shows how an expert system control logic was designed with closed-loop genetic algorithm optimization to control the production of emerging subsea oil wells in order to maintain continuous supply to the platform's treatment process and correct disturbances. For this purpose, a genetic algorithm was developed that calculates the best separation condition for the process for each imposed production flow rate and controls the change of the process setpoint to this optimal condition via an expert control system. Several simulations were performed to demonstrate the system's operation, and it was seen that the productivity of this system was superior to the conventional system in all simulations.

Keywords: Expert system, genetic algorithms, FPSO, process control, Oil wells.

Resumen

Incrementar la productividad de una unidad de producción de petróleo es un desafío en entornos como el presal brasileño. Como el control del proceso de tratamiento de petróleo es esencial para la continuidad de la plataforma y considerando que la mayoría de las unidades actuales utilizan control de retroalimentación convencional, surgió la necesidad de optimizar el sistema de control del proceso de separación, control de flujo de pozo y llenado de tanques de lastre para reducir el número y tiempo de paradas del proceso. Este artículo muestra cómo se diseñó una lógica de control tipo sistema experto con optimización mediante algoritmos genéticos de circuito cerrado para controlar la producción de pozos petroleros submarinos emergentes con el fin de mantener un suministro eléctrico continuo al proceso de tratamiento de la plataforma y corregir desórdenes. Se desarrolló un algoritmo genético que calcula la mejor condición de separación para el proceso para cada flujo de producción impuesto y ordena el cambio del punto de ajuste del proceso a esta condición óptima a través del sistema de control experto. Se realizaron varias simulaciones para mostrar el funcionamiento del sistema, y la productividad de este sistema fue mayor que la del sistema convencional en todas las simulaciones.

Palabras clave: Sistema experto, algoritmos genéticos, FPSO, control de procesos, pozos petroleros.

Resumo

Aumentar a produtividade de uma unidade marítima de produção de petróleo é um desafio em ambientes como o pré-sal brasileiro. Como o controle do processo de tratamento de óleo é essencial para a continuidade da plataforma e tendo em vista que a maioria das unidades atuais utiliza controle feedback convencional, surgi a necessidade de otimização do sistema de controle do processo de separação, controle de vazão dos poços e enchimento dos tanques de lastro para reduzir o número e tempo dos shutdowns do processo. Esse artigo mostra como foi concebida uma lógica de controle do tipo sistema especialista com otimização por algoritmos genéticos em malha fechada com o controle da produção de poços de petróleo surgentes submarinos a fim de manter a alimentação do processo de tratamento da plataforma de forma contínua e a corrigir distúrbios. Para isso foi elaborada um algoritmo genético que calcula qual a melhor condição de separação para o processo para cada vazão de produção imposta e comanda a alteração do setpoint do processo para essa condição ótima via sistema especialista de controle. Várias simulações foram realizadas para mostrar o funcionamento do sistema, sendo visto que a produtividade desse sistema foi superior ao sistema convencional em todas as simulações.

Palavras-chave: Sistema especialista, algoritmos genéticos, FPSO, Controle de processo, Poços marítimos.

Introduction

The oil industry is essential to modern life. Whether for the generation of electrical energy, movement of vehicles or even as an input for the manufacture of various components, where oil consumption becomes important even for measuring the development of a nation and will continue to be essential for many decades until they are found economically viable substitute products for all its applications, Costa (2014, p. 4).

Second Chaves (2021) the Brazilian offshore production is much larger than onshore production and therefore deserves to be highlighted in its analysis. In recent years, offshore oil exploration in the Brazilian pre-salt has gained prominence due to its volume and social contribution to the country. See figure 1 for an FPSO (floating, production, storage and offloading) platform used in the Brazilian pre-salt.

On oil platforms, wells are normally operated manually by opening or closing the production choke valve of each well. In many cases the plant operates below the nominal production level, as valve activation to increase well production depends on visualization of the deviation and operator action to correct this deviation and this does not always happen at an adequate speed, in addition to the Changing the production setpoint only occurs after analysis by engineers in the area and not in a continuous and optimized manner for each operational condition imposed on the process.

Engineering techniques and knowledge for operating machines, equipment, tools and/or applications with decision-making capabilities are important for improving systems, where among several technologies that have already been developed, we have genetic algorithms and expert systems as techniques these have been successfully applied throughout the world, according to Bello et al. (2016); Chaves (2021), states that with the need for quick and efficient solutions for process control, we can promote less need for personnel for the operation of plants with significant improvement in the process result with the techniques mentioned, thus obtaining cost reduction and increased production.

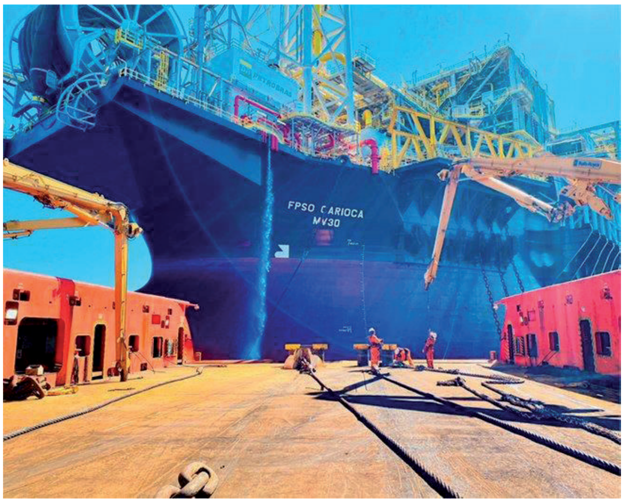

Figure 1: Petrobras FPSO-type platform leaving the shipyard.
Source: Petrobras, 2021.

Although traditional control is widely used due to its ease of implementation and the large amount of information already prepared about its models, there is no guarantee that these models are the most suitable for modern processes, as the complexity of plants has been increasing with age. Time and therefore the complexity of control systems should follow the same rhythm. Nunes (2010) confirms this when saying that “strict control of offshore processing variables guarantees operational continuity, but does not economically optimize processing” and reinforces this view as he states that “Emphasis should be given to the global trend greater complexity of processing plants due to the search for oil in regions previously considered economically unviable or unattractive”, a description that fits the situation under study. Still as a justification, we have that the technological challenges for oil exploration in ultra-deep waters permeate conventional exploration and production techniques. According to Campos et al. (2017), environments that present extreme situations of temperature, pressure and the presence of contaminants, such as CO_2, require new approaches to enable production with reference efficiencies for the processes.

Thus, this research will aim to show how the implementation of an expert system with genetic algorithms for optimizing the control setpoints of separator vessels can be used as a new production technology for a real FPSO-type platform currently installed in the Brazilian pre-salt, focusing on obtaining prospects for production gains in order to add value to Petrobras and other companies in the sector, contributing to a more stable platform operation and sustainable industrial development, with a safe working environment and responding to the following research question: "How to control the production process using an expert system and genetic algorithms in order to safely increase the production of an FPSO-type platform?"**.**

Methodology

First, a simulation of the process was carried out with the characteristics present in the platform under analysis in order to predict the behavior of the process reliably. For this, the simulation developed, validated and presented by Chaves (2021) was used as shown in the figure below:

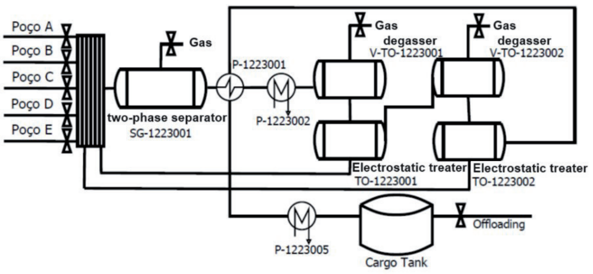

Figure 2: Oil treatment process flowchart in current configuration.
Source: Chaves (2021).

In figure 2 it is possible to observe that the process begins with the wells and ends in the cargo tanks, where the current condition of the platform under analysis is a process formed by five producing wells, a three-phase separator that operates as two-phase due to the non-significant production of water through the wells currently, four treatment vessels (2 degassers and 2 electrostatic), two shell and tube heat exchangers, a compact plate heat exchanger and a platform storage tank (Cargo tanks). In addition to the equipment previously mentioned, the plant contains a compact plate heat exchanger for heating water for the oil desalination stage, however it was not included in the simulation, as this stage is not currently being used for real conditions, therefore the dilution step for desalination was not included.

In the simulation carried out and seen in figure 3, we focus on the interface between the wells and the process, in this case the modeling of well production through the choke and the operational conditions of the separator vessels becomes important, which will be controlled by the expert system with genetics algorithms, as they are the ones who will receive the production from all the wells and still have their output controlled by the system created. Thus, the equations that are used to model the separator according to what is presented in the work of Nunes (2010) are:

$$\frac{dh_L(t)}{dt} = \frac{L_{in}(t) - L_{out}(t)}{2C\sqrt{[D - h_L(t)]h_L(t)}} \tag{1}$$

$$\frac{dP(t)}{dt} = \frac{P(t)(G_{in}(t) - G_{out}(t) + L_{in}(t) - L_{out}(t))}{V - V_L(t)} \tag{2}$$

$$L_{out} = 2{,}4.10^{-4}.C_v f(x)\sqrt{\frac{\Delta P_v}{\rho_L/\rho_w}} \tag{3}$$

$$G_{out} = 2{,}4.10^{-4}.C_v f(x)\beta\varepsilon P(t)\sqrt{\frac{(P(t) - P_2)}{P(t)ZT\left(\frac{\rho_g}{\rho_{ar}}\right)}} \tag{4}$$

$$V_L(t) = \frac{C_1 {D_1}^2}{4}\left[arccos\left[\frac{D_1 - 2h_L(t)}{D_1}\right] - \left[2\frac{\sqrt{(D_1 - h_L(t)h_L(t))}}{D_1}\right]\left[\frac{D_1 - 2h_L(t)}{D_1}\right]\right] \tag{5}$$

Where:

$V_L(t)$: Volume of liquid in the vessel (m^3);
$V(t)$: Vessel volume (m^3);
ρ_L: Specific mass of the liquid (kg/m^3);
ρ_G: Specific mass of the gas (kg/m^3);
ρ_{ar}: Specific mass of air (kg/m^3);
$L_{in}(t)$: Volumetric flow of liquid entering the vessel (m^3/s);
$L_{out}(t)$: Volumetric flow of liquid leaving the vessel (m^3/s);
$G_{in}(t)$: Volume of gas entering the vessel (m^3/s);

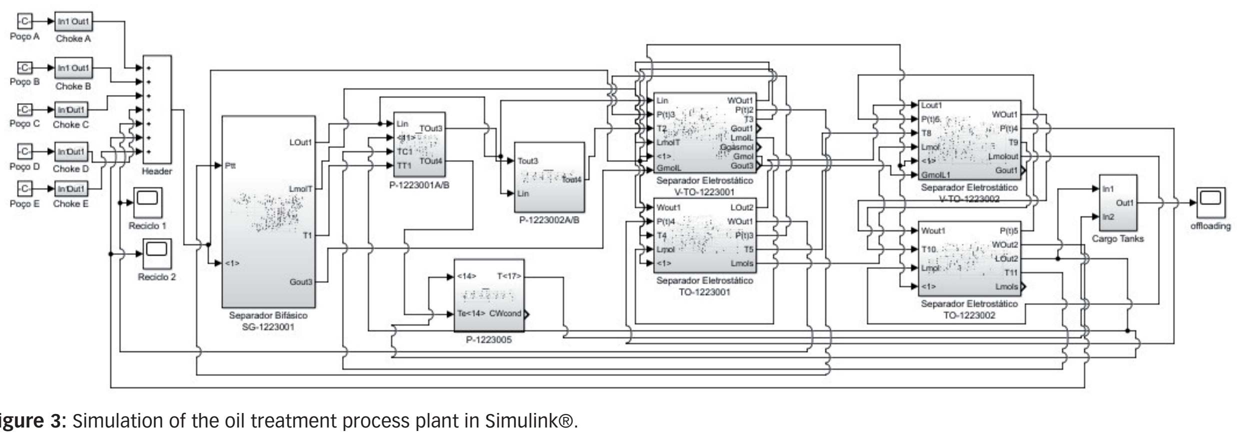

Figure 3: Simulation of the oil treatment process plant in Simulink®.
Source: Chaves (2021).

$G_{out}(t)$: Volume of gas output in the vessel (m^3/s);
$h_L(t)$: Height of the liquid to the interphase (m);
$P(t)$: Vessel pressure (bar);
C: Separator length (m);
D: Diameter of the separator (m);
ε: Isentropic expansion factor;
β: Opening dependent;
K: isentropic exponent;
Z: Compressibility factor.

Next, we can visualize the application of these variables in figures 4 and 5, which show how the relationships are presented in the equipment.

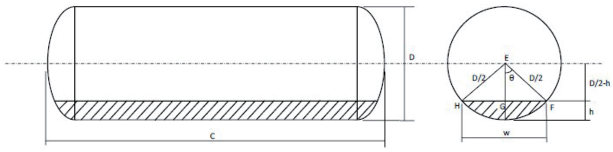

Figure 4: Typical separator dimensions.
Source: De Medeiros (2021).

In this study, we need to find a solution space for the production input flows that maximizes the objective function, generating a setpoint choice function that guarantees this. As the method is heuristic, it is possible to find several optimal solutions and it will be necessary to evaluate the one that is best suited for practical application via genetic algorithms, which have a methodology like that in figure 6.

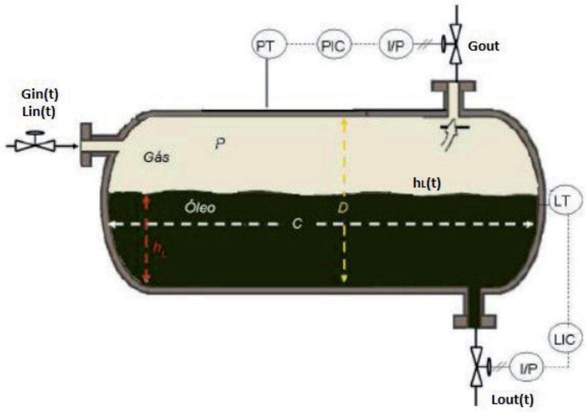

Figure 5: Scheme of variables deduced in the equipment design.
Source: Silva (2013).

As can be seen above, the search for the best solution using the genetic algorithm reduces the computational effort depending on the size of the chosen population and the criteria used to finalize the method. With this, a previously unsolvable problem can be turned into a problem with approximate solutions, which can be used in practice to gain in the process. It is noted that in the end a result will be obtained which, in this case, is a convergence that will occur through the maximization of the objective function, with the number of iterations that it reports being interpreted by the number of generations that will be in the genetic algorithm.

The processing of the expert system that operates the control of setpoints and override and that of the well control loop will be in parallel, because as Simões (2007, p.

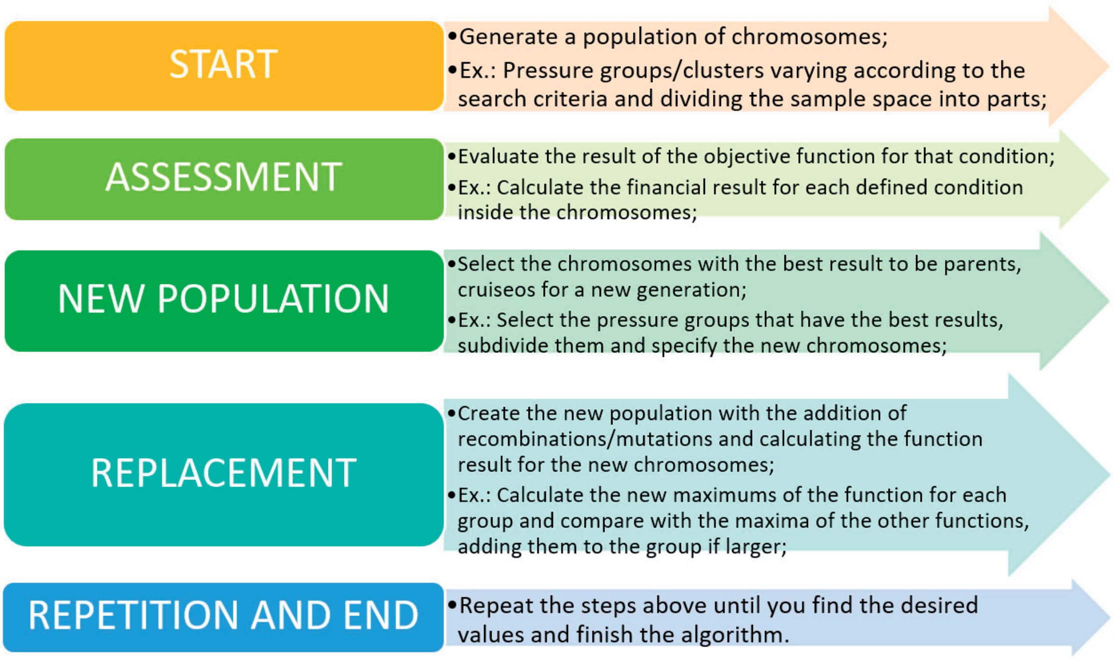

Figure 6: Basic flow chart for using genetic algorithms to optimizations tasks.
Source: Prepared by the author (2023).

64) states, "parallel processing is fast. The fuzzy controller completes the processing task without involving many calculations, and thus the processing speed is increased."

To close the control loop, we need an efficient controller to reduce the error to zero between the setpoint and the measured value regardless of the disturbance that occurs. The conventional PID (Proportional, Integral and Derivative) system is widely used for conventional loops, but in the present study it needs improvement, as the flow control dynamics are complex, as they change with the entry and exit of each well and even with the interaction that occurs with the control of vessel level and pressure. To solve this problem, a Fuzzy-PID controller was designed to reset the error and adapt to the changes that may occur in the behavior of the wells with the process without needing to re-tune.

Results and discussions

The models presented in the methodology were implemented in Matlab®'s Simulink® in the form of circuits, as an example shown in figure 3. As boundary conditions to carry out the simulation, real, current information present in the FPSO's oil processing for the points where there is measurement, based on the analysis of variables in Plant Information®, and some information that is not subject to continuous measurement because it is fixed, such as equipment dimensions, was removed from the platform design premises. Four simulations were carried out to validate the models, with the 3 simulations of the plant as a whole being carried out in the time unit of minutes and the heat exchanger simulation in the time unit of seconds. These simulations are presented in the work of Chaves (2021).

As already described, the 5 wells production depends on their head pressure and the opening of the surface control choke valve. The various equipment that is interconnected to promote the treatment of oil on the platform has conventional feedback controls in its structures to guarantee the stability of the treatment on the equipment. Therefore, it is interesting to take advantage of this already implemented logic, as it does not present additional cost to use them, in addition to following the configurations recommended in the broad theoretical framework studied, such as that exported by Nunes (2010) and Garcia (2017).

To implement the controls in the simulation, we performed an open-loop test. This test involved a step-type disturbance, increasing the controller output by 0.48 mA. The objective was to evaluate the step deformation in the target variable. Using this data, we analyzed the process behavior using three methods: Ziegler Nichols (ZN), Smith Method (MS) and Sundaresan and Krishnaswamy (SK). These methods helped us define the parameters Kp, O, T and for each case. Figures 7 and 8 and Table 1 illustrate the correct application of these methods in measuring the response curve. They demonstrate the adherence to the results of each equipment.

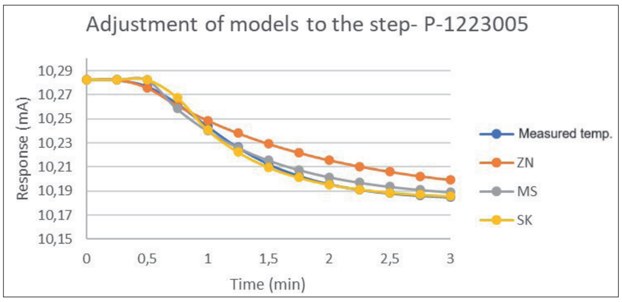

Figure 7: Adjustment of models to the 0.48 mA step at the controller output for P-1223005.
Source: Prepared by the author (2023).

Table 1: Possible tuning for temperature and performance indicators for P-1223005.

Open loop response tunning	Tunning	Mode	IAE*	ISE*	ITAE*	ITSE*	CE*
Ziegler and Nichols	Ziegler and Nichols	Slave	7.41	6.87	30.17	15.69	0.0175
Ziegler and Nichols	Ziegler and Nichols	Regulatory	0.66	0.03	4.54	0.16	0.0292
Ziegler and Nichols	IMC	Slave	11.50	7.69	91.56	36.93	0.0019
Ziegler and Nichols	IMC	Regulatory	3.89	0.72	37.05	4.46	0.0063
Smith's method	IMC	Slave	8.80	7.97	36.69	22.99	0.0037
Smith's method	IMC	Regulatory	0.86	0.05	6.65	0.27	0.0088
Sundaresan and Krishnaswamy	IMC	Slave	12.12	7.29	111.00	42.78	0.0020
Sundaresan and Krishnaswamy	IMC	Regulatory	6.15	1.66	63.30	11.61	0.0056

*Note: IAE (integral of the absolute value of the error), ISE (integral of the squared error), ITAE (integral of the absolute value of the time-weighted error), ITSE (Integral of squared errors multiplied by time), CE (control effort).

Source: Prepared by the author (2023).

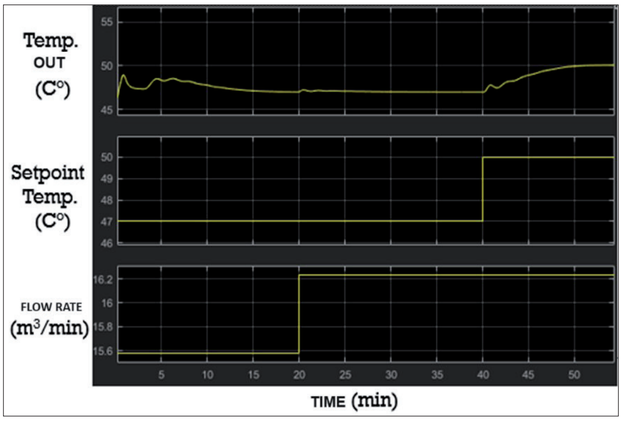

Figure 8: Temperature control evaluation chart in P-1223005.
Source: Prepared by the author (2023).

In figure 7 we have the adjustment of the models to the step performed, SK with the best representation, followed by Ziegler and Nichols which can be seen in table 1 as it has the best tuning indicators. The response to this can be seen in figure 8 with a test that shows the rapid response to steps taken in the flow rate and setpoint with return to the required condition quickly and with stability, a stability that was confirmed when carrying out the system response analysis as can be seen in figure 9. The same tests were carried out for the level and flow controllers and the results were similar, thus obtaining a simulation that is a good representation of that carried out for the analysis of the implementation of artificial intelligence systems and process optimization.

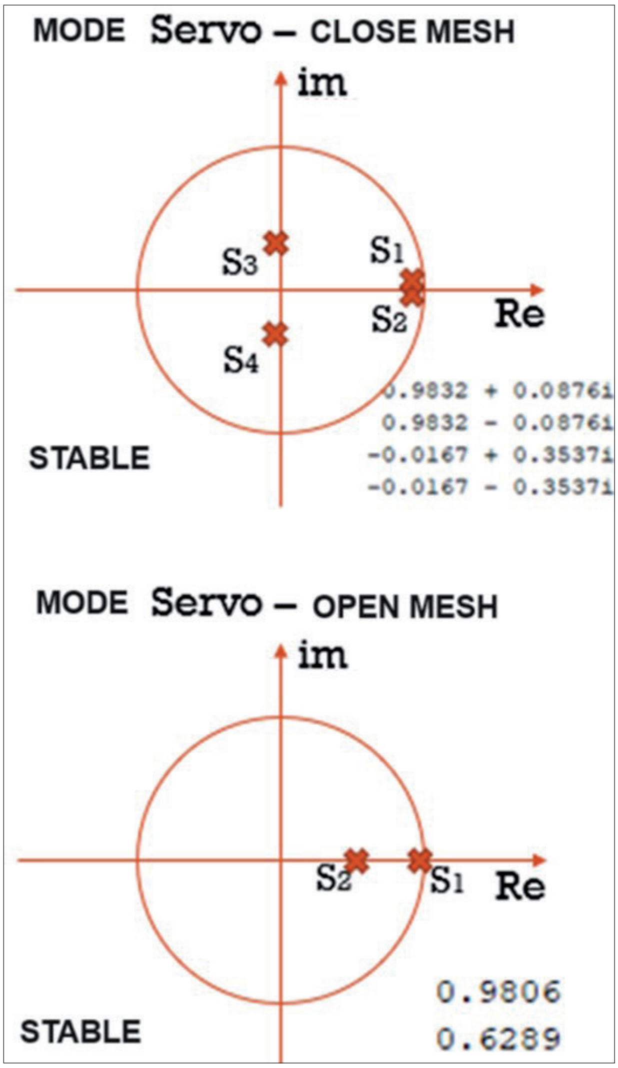

Figure 9: Temperature control evaluation chart in P-1223005.
Source: Prepared by the author (2023).

The process studied is more profitable the more the relationship between what is produced from oil and gas approaches its maximum when we multiply its volumes produced by the sales revenue, given a scenario in which costs do not change when we change the forms of production via change of setpoint for the installed structure. Therefore, a study was carried out using genetic algorithms to evaluate the maximum points of this objective function and the respective operating setpoints.

With the controls already implemented in this work, it is possible to control well production, operating temperatures, separator pressures and vessel levels. When analyzing these factors, we find that the level has little impact on production, as it does not significantly affect the separation rate. The temperature already influences a lot, but in the case under analysis it cannot be changed, since above the temperature currently held in P-1223002 there is a risk of boilover in V-TO-1223001 if it is exceeded or occurs lack of process control, this is not recommended, as it may reduce separation efficiency and may even make it impossible to exchange P-1223001. This leaves the pressure and supply flow to be studied in order to optimize the objective function. Given that the ideal flow range to be studied is the one that is close to the nominal value of the plant and the pressure range is the one referring to each stage of separation in each separator vessel in the possible range of pressure control and operational limits, then it was chosen carry out the study by varying the flow rate of the feeding plant as a function of the pressure at each separation stage.

A genetic algorithm was created that received the flow and pressure information from each stage as a genetic code and discretized it, within the limits normally used for process control, into 8 chromosomes for pressure, equally distributed between the process variation limits, and divided into 4 clusters/flow populations, equally spaced within the studied limits with 8 chromosomes within each cluster, where the result of the objective function was calculated so that the setpoint control could be optimized.

For the analyzed system, the objective function is formed by the revenue obtained from the sale of oil and gas products, which is dependent on the liquid vapor balance defined by the imposed setpoint conditions, thus obtaining the result of the process, however, without practically changing the cost conditions of the plant with the variations in the operating conditions, since the costs remain fixed even if the setpoints change, and the costs of acquiring meters and controllers are negligible compared to the revenue obtained from the process, therefore, in the end, we have as an objective function the form below:

$$J = RG\Sigma G + RL\Sigma L \tag{6}$$

With J as the result of the objective function in R$ per unit of time, RG is the revenue from the sale of gas in R$/m^3, RL is the revenue from the sale of oil in R$/m^3, G is the flow rate of gas produced in m^3 per unit of time and L is the flow rate of oil produced in m^3 per unit of time.

See figures 10, 11 and 12 for the results found for the equipment for a study carried out in 3 generations, enough generations to find with good precision the optimal operating pressures and revenues per input flow, with the first generation resulting from the input information from the genetic code and the second and third generation specified based on the choice of pressure that brought the greatest result for the objective function for a tournament-type selection algorithm that rewrites the chromosomes

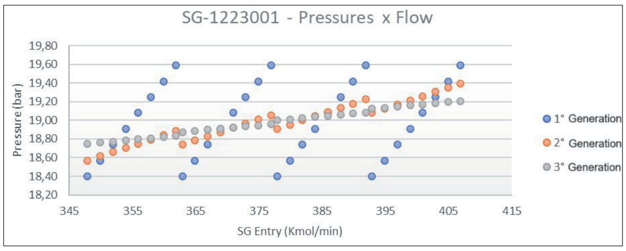

Figure 10: Pressure per flow per generation for SG-1223001.
Source: Prepared by the author (2023)

into 8 parts equally distributed around the maximum points found with a dispersion step of 4 times smaller than that of the previous generation, thus generating a crossing-over type reproduction that guarantees convergence to the maximum value for the flow under study.

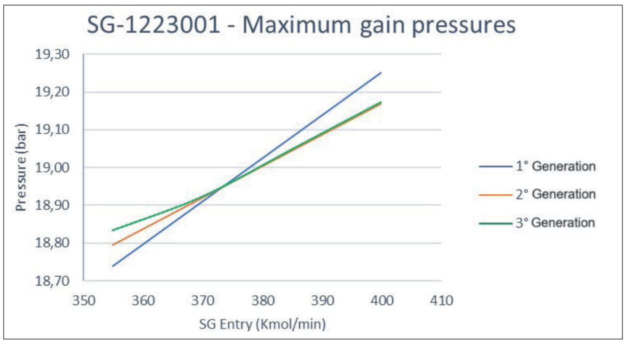

Figure 11: Pressure per flow per generation for the highest objective function result SG-1223001.
Source: Prepared by the author (2023).

Note that the financial result increases with the increase in input flow, as expected, since the higher the input production, the higher the result. In the case of pressure, for each flow level, the pressure that maximizes the objective function was found using the search technique provided by the genetic algorithm.

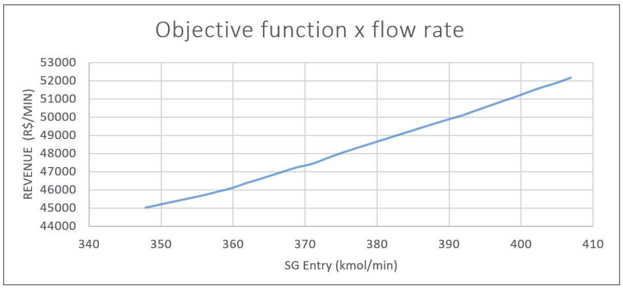

Figure 12: Result of the flow objective function for the optimal pressures for SG-1223001.
Source: Prepared by the author (2023).

The search begins in the first generation with pre-determined values that are the operational limits of pressure variation. In the second generation, the father is chosen as the pressure value of the chromosome of the first generation that follows the maximum pressure value found, and the mother is chosen as the pressure prior to the maximum pressure found of the input chromosome, thus generating descendants that ensure that their genetic material contains the information necessary to refine the data, thus obtaining a greater proximity to the maximum value of the function, but still with a linear view around the central maximum point found, since the chromosomes were generated from the division of the interval where the maximum was found into 8 equal parts, therefore linear. At the end of the third generation, we have the pressure value where the maximum was found, representing each flow rate as almost a single curve with little slope, gray points, showing that the pressure function that maximizes the objective function in terms of pressure and flow rate in a satisfactory way was found. With this function, you can now optimize the automatic setpoint in order to increase operating revenue. Subsequently, the same study was carried out for V-TO-1223001, obtaining the following results in figures 13, 14 and 15.

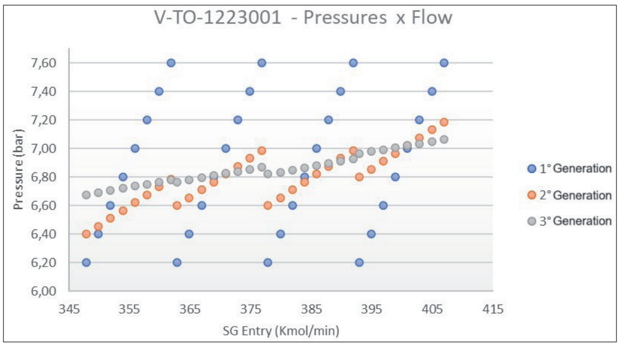

Figure 13: Pressure per flow per generation for V-TO-1223001.
Source: Prepared by the author (2023).

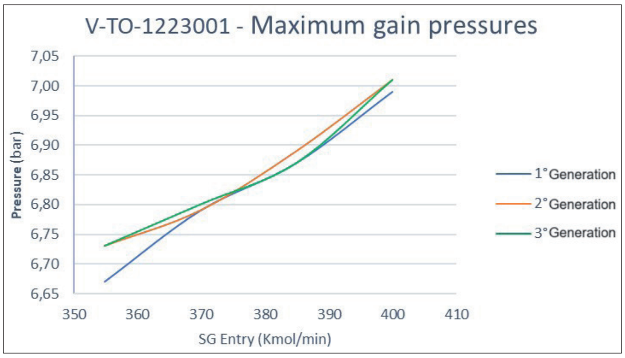

Figure 14: Pressure per flow per generation for the largest result of the objective function V-TO-1223001.
Source: Prepared by the author (2023).

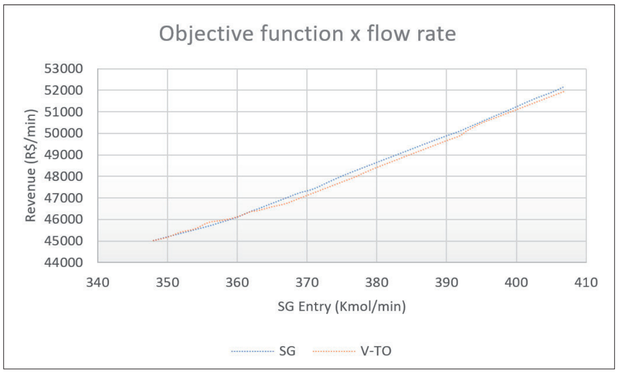

Figure 15: Result of the objective function by flow for the optimal pressures for the SG and V-TO-1223001.
Source: Prepared by the author (2023).

We can observe that the behavior is similar to what was found for the SG, with the result of the objective function being slightly lower, which is justified by the greater degree of depressurization that the fluid was in at this stage. It is worth noting that in both cases the nonlinear behavior of the liquid-vapor equilibrium was observed to have little influence, since the pressure is far from the critical pressure, which is around 50 bar, and taking into account that the pressure range for analysis was only 1.4 bar.

With the two objective function curves and their setpoint data, a fourth generation was created for analysis, using the operating pressures that maximize the objective function for both pieces of equipment at the same time to generate the final curve of optimal revenue. Thus, it was possible to see the optimization of the objective function with the interaction between the vessels, as can be seen in figure 16.

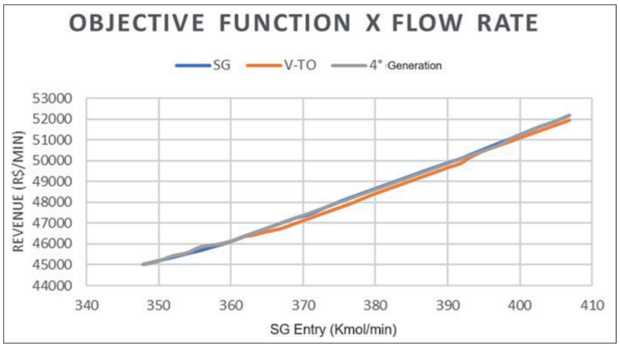

Figure 16: Result of the objective function by flow rate for the optimal pressures in the fourth generation.
Source: Prepared by the author (2023).

This allows for optimal pressure setpoint control. It is also worth noting that during the entire process of searching for the optimal operating point, a search mutation was performed in parallel with randomly created chromosomes in order to calculate gain points based on the variation in pressures and flows within the population space, and compared with the optimum found for the 4th generation under analysis. No mutation points were found at maximums greater than those found in the generation analyses, thus showing that we are not operating at a local maximum, but rather at a global maximum. With the study completed, it was possible to implement an expert setpoint and override control system for the process. See below a test that shows the automatic change of setpoint for 3 different flow levels for the process in the SG. We have a step-type disturbance with a 4% reduction in production at 30 minutes and then an 8% increase in the SG input production at 60 minutes. Note that the setpoint automatically alternates between 19.1 bar, 19 bar and 19.25 bar according to changes in the flow rate. It is worth noting that the process has a fixed setpoint of 19.3 bar, regardless of the flow rate, in its design, and with the application of this technology, genetic algorithms with an expert system, we have the possibility of production with the optimized recipe and thus have significant gains. Also note that the liquid output flow rate (Lout) and gas flow rate (Gout) follow the control logic and the level imposed by the variation in the process input, but with a slight change based on the setpoint control, thus optimizing the recipe. Note that the results found for this are similar to those presented by Araújo Júnior (2007).

In addition, the expert system provides override control, thus helping the SIS (Safety Instrumented System) in the process. See below two tests, one of which causes a disturbance in the operating pressure that causes the pressure limit established for the SIS to be reached, 19.6 bar, thus activating the override control of the plant's feed flow via neuro-fuzzy logic that reduces the flow, preventing the pressure from rising any further, despite a disturbance having been programmed that takes the pressure to 20 bar, and until the pressure is reduced and thus the process stability returns. Note that the flow control already acts at the beginning of the process to generate the return of the flow to the setpoint even with the increase in pressure on a ramp, since the feed flow is reduced with the increase in pressure naturally, but when this pressure reaches the limit established by the SIS, the flow undergoes a more significant reduction in order to remove the process from the limit region. Note that when the pressure is reduced below the limit again as can be seen in figures 17 and 18, the flow returns to the normal process setpoint, since the instability has already been overcome. It is worth remembering that these response graphs presented agree with what is presented by Duarte (2020) in his work, thus corroborating the results.

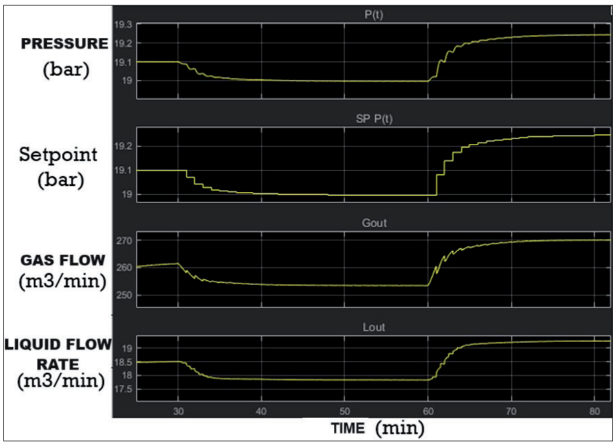

Figure 17: Automatic setpoint control for two flow disturbances.
Source: Prepared by the author (2023).

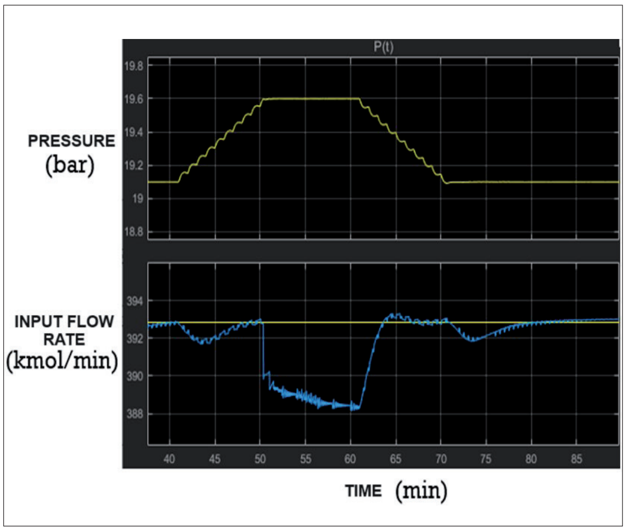

Figure 18: Override control actuation when the limit pressure is reached.
Source: Prepared by the author (2023).

In figure 19 we can see the actuation of the override flow control to raise the level in the vessel, where the flow is reduced when the established limit of 2.5 m of level is reached, despite having been programmed to reach 2.8 m, where it can be seen that the level reduces with the reduction of the flow, where then the flow returns to normal control and tends to normalize, however the level increases again and then reaches the limit again, in the end we can see that the override control is activated 4 times until the nominal flow is reached with the normal level.

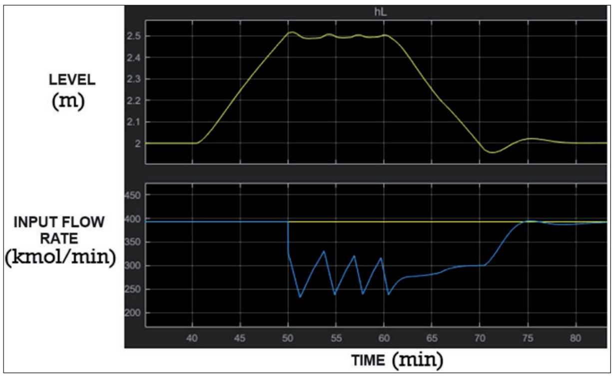

Figure 19: Actuation of the override control when reaching the limit level.
Source: Prepared by the author (2023).

The proposed final expert system is composed of rules such as those exemplified in figure 20, in the same format proposed by Campos (2016, p. 4) shown the theoretical framework, thus obtaining what is necessary for the setpoint and override control of the plant:

If {(P1(t))} is smaller than the {(upper limit)} and greater than the {(lower limit)} then ENABLE {(setpoint control by genetic algorithms f(x))};

If {(P1(t))} is greater than the limit then ENABLE {(flow override control)} and DISABLE {(setpoint control by genetic algorithms f(x))};

If {(P1(t))} is smaller than the {(lower limit)} then ENABLE {(flow override control} and DISABLE {(setpoint control by genetic algorithms f(x))};

If {(Nível1(t))} is smaller than the {(upper limit)} and greater than the {(lower limit)} then ENABLE {(setpoint control by genetic algorithms f(x))};

If {(Nível1(t))} is greater than the limit then ENABLE {(flow override control)} and DISABLE {(setpoint control by genetic algorithms f(x))};

If {(Nível1(t))} is smaller than the {(lower limit)} then ENABLE {(flow override control} and DISABLE {(setpoint control by genetic algorithms f(x))};

Figure 20: Proposed expert system for setpoint and override control.
Source: Prepared by the author (2023).

Note that in the end the proposed system will have at least 36 rules for the process studied here, but does not require a high computational effort, as it is composed of simple rules. Campos (2016) proposed an expert system for controlling the temperature of LUBNOR furnaces that is similar to this one in relation to the syntactic structure, but with different functions and forms of action, because in this case we have the study in genetic algorithms with override control and the control structures explained here keeping the system stable even with current disturbances and not just maintaining a setpoint.

Due to the innovative nature of the adopted solution, a patent application was filed, number BR 10 2022 015577 1, entitled "Expert system and setpoint control method by genetic algorithms and override control" by Petrobras S.A.

Finally, an assessment was made of the financial gain from applying the technology to the FPSO studied, given that the implementation of the expert system with genetic algorithms allows the plant to always operate at the optimum setpoint condition, regardless of the flow condition, thereby generating a gain related to the difference in production achieved in this way, in certain periods of time, in relation to what is produced during the time in which the plant does not operate at its optimum condition by waiting for the operator's reaction time to change the process conditions, which currently operate without automatic setpoint control, when there is a reduction in efficiency or disturbance in the process and which require manual action by the operator. Note that the difference in production between the two methods depends on the plant operator and the moment in which the reduction in efficiency occurs, thus an average gain of 25.73 US$/h was calculated during the operation of the process by defining the optimum pressure setpoints, compared to the objective function with the genetic algorithm, since working at the optimum points in relation to the setpoints currently operated. With the data above, with the current oil price at 87.51 US$/bbl and the dollar at 5.46 R$/US$, using an internal or attractive rate of return of 10% per year, considering that Petrobras has 72 platforms under similar production conditions and that can undergo the same optimization and that Petrobras' current business plan is for 5 years from 2022 to 2026, it was possible to calculate a gain of US$ 225,417.58 (R$ 1,230,780.00) in financial return for 1 platform per year and up to US$ 67,677,191.03 (R$ 369,517,463.28) in delta EVA for 72 platforms considering the company's 2022-2026 business plan.

Conclusions

The study showed that the setpoint adjustment must be performed by an expert system that controls the change in setpoint according to the change in some variable of interest and based on a study carried out in genetic algorithms, since the setpoint must always be the one that maximizes the concession result if the process is within the operational limits. The study in genetic algorithm is what guarantees the maximization of the objective function and with it the functions that parameterize the setpoint control are generated. The study as a whole showed gains when changing the setpoint in an optimized way and thus greater results in production. For the setpoint change ranges studied, no difficulty was found for the control system to adapt to the change.

It is suggested that the work carried out here also be carried out in CFD (Computational Fluid Dynamics) in order to improve the accuracy of the models and controls and thus obtain an optimization as close as possible to reality in terms of financial results. It is considered that the objective of the research was achieved and that the development of more work in this area and with the tools proposed here can bring more advances to the industry and to scholars in the area.

References

1. **ARAÚJO JÚNIOR, José Medeiros de.** *Técnicas de Inteligência Artificial para a geração Dinâmica de Set Points para uma Coluna de Destilação.* **Dissertação de Mestrado. Universidade Federal do Rio Grande do Norte. 2007.**
2. **BELLO, Opeyemi et al.** *Application of artificial intelligence techniques in drilling system design and operations: a state of the art review and future research pathways.* In: SPE Nigeria Annual International Conference and Exhibition. OnePetro, 2016.
3. **CAMPOS, M. C. M. M.** *Aplicações de Controladores "Fuzzy" na Petrobras.* Centro de Pesquisa e Desenvolvimento – CENPES. 2016.
4. **CAMPOS, Mario CMM et al.** *Intelligent system for start-up and anti-slug control of a petroleum offshore platform.* In: OTC Brasil. OnePetro, 2017.
5. **CHAVES, José Andersands Flauzino.** *Controle plantwide do processo de tratamento de óleo de um FPSO do pré-sal brasileiro empregando lógica neuro-fuzzy com otimização por algoritmos genéticos e controle override.* Dissertação. Universidade Federal de Sergipe. Aracaju-SE. 2023.
6. **CHAVES, José Andersands Flauzino; DA SILVA, Flávio Vasconcelos; FONSECA, Rodolpho Rodrigues.** *Modelagem e simulação dinâmica do processo de tratamento de óleo em um FPSO.* Apresentação de trabalho. III SEMINÁRIO DE PESQUISA EM
7. **COSTA, Susiane Marques.** *A exploração do pré-sal e o futuro brasileiro.* Trabalho de conclusão de curso. UNB. 2014.
8. **DE MEDEIROS, Márcio Lindemberg Bezerra; DE OLIVEIRA JUNIOR, Antonio Martins; FONSECA, Rodolpho Rodrigues.** *Gain scheduling control applied to oil and gas separator level loop.* Research, Society and Development, v. 10, n. 4, p. e55010414397-e55010414397, 2021.
9. **DUARTE, Robson A. et al.** *Ganhos de Produtividade em um Circuito de Britagem devido à Aplicação de Controle Override.* In: Congresso Brasileiro de Automática-CBA. 2020.
10. **ENGENHARIA QUÍMICA.** Universidade de Federal de Sergipe. 2021.
11. **NUNES, Giovani Cavalcanti; DE MEDEIROS, José Luiz; ARAÚJO, Ofélia de Queiroz Fernandes.** *Modelagem e controle da produção de petróleo: aplicações em Matlab.* Editora

Blucher, 2010.

12. **PETROBRÁS**. *Petrobrás.* Disponível em: http://www.petrobras.com.br. Acesso em: 10 de novembro de 2021.

13. **SILVA, Filipe Reolon da.** *Estudo de um novo sistema de separação primária de gás-óleo-água para plataformas de petróleo.* Trabalho de conclusão de curso. Universidade Federal do Rio Grande do Sul. 2013.

14. **SIMÕES, Marcelo Godoy; SHAW, Ian S.** *Controle e modelagem fuzzy.* Editora Blucher, 2007.