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ECORFAN-Democratic Republic of Congo

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Presentation of the Content

In the first article we present, *Thermodynamic analysis of nuclear plants: A virtual perspective*, by Franco-Martínez, David & Sampayo-Meneses, Alberto, with adscription in the FES Aragón, Universidad Nacional Autónoma de México, as the next article we present, *Virtual reality forklift simulator - VRFS*, by Cortes-García, Alicia, Valencia-García Alejandro Cesar, Rodríguez-Miranda, Gregorio and Mendoza-Hernández, Guillermo, with adscription in the Universidad Tecnológica de San Juan del Río as the next article we present, *Domotic control by codification of electromyographic signals and network sockets*, by González-Silva, Marco Antonio & Hernández-Pérez, Faride, with adscription in the Universidad Autónoma de la Ciudad de México and Universidad Politécnica Metropolitana de Hidalgo, as the last article we present, *Determination of the solar fraction for optimized parabolic concentrator solar collector networks*, by Lizárraga-Morazán, Juan Ramón & Picón-Núñez, Martín, with adscription in the Universidad de Guanajuato.

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Article

Thermodynamic analysis of nuclear plants: A virtual perspective

Análisis termodinámico de plantas nucleares: Una perspectiva virtual

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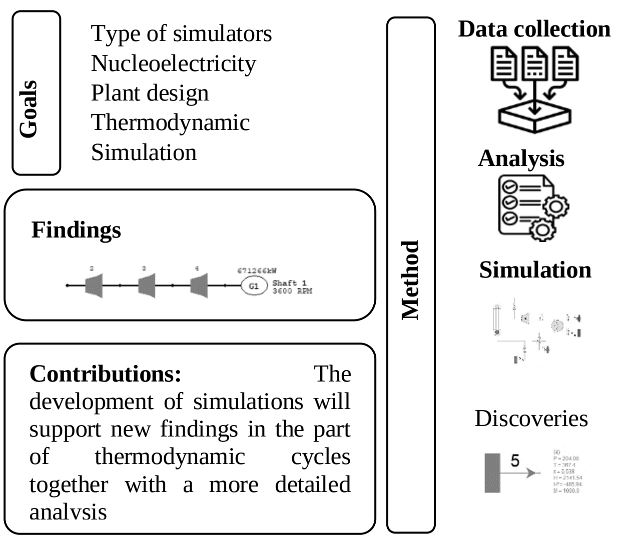
Abstract

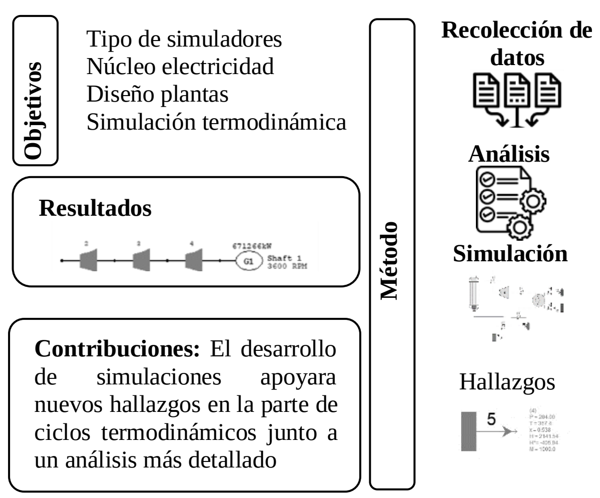
This article aims to study the generation of electricity through nuclear energy, to do so, it goes through the other ways to obtaining energy, until reaching nuclear energy, where the research is deepened, emphasizing nuclear reactions and operation. of nuclear power plants. Once the theory was understood, simulation projects were carried out in software, previously explained, the simulations were matched and complemented for a greater understanding of the theory. This article allows the understanding for a particular case, applicable to different projects promoted by Thermoflex, since there are no guides or tutorials in Spanish and those that exist in other languages, they are not very varied.



Thermodynamics, Simulation, Thermoflex

Resumen

Este artículo tiene como objetivo estudiar la generación de electricidad mediante la energía nuclear, para ello, se pasa por las otras formas de obtención de energía, hasta llegar a la nuclear, en donde se profundiza la investigación, haciendo énfasis en las reacciones nucleares y la operación de las centrales nucleares. Una vez comprendida la teoría, se realizaron proyectos de simulación en software, previamente explicados, las simulaciones se empatan y se complementan para un mayor entendimiento de la teoría. Este artículo permite el entendimiento para un caso particular, aplicable a diferentes proyectos impulsados por Thermoflex, pues como ya se mencionó, no existe guías o tutoriales en español y los que existen en otros idiomas, no son muy variados.



Termodinámica, Simulación, Thermoflex

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Introduction

The aim of this research is to uncover the underlying factors that contribute to the operation and functioning of power plants. To this end, emphasis had placed on the origins of electricity generation.

In modern life, it is undeniable that electrical energy is essential to satisfy all the needs that today's society requires, to address this, the various methods of generating electrical energy were addressed, taking the time to analyze and focus on them.

The focus of this project is on nuclear energy, it is important to understand the fundamental aspects, such as the atomic nucleus, conceptually, as well as its behavior during the physicochemical processes of obtaining energy.

For research purposes, a fundamental point is the nuclear power plant, which involves studying the various aspects that allow its correct operation, Safety conditions, the fuel cycle, and even social controversies are among the topics discussed.

The importance of virtual tools, specifically simulation software, which are fundamental parts of this project, has been made known. There is no doubt that virtual tools are becoming more common and can assist in multiple areas, especially in this scenario, the usefulness in favor of facilitating understanding and helping the study of different topics stands out, virtually exemplifying them is beneficial for some.

The main project of this work is to present the results of a simulation of a nuclear plant. In two different software, a related project, the proposed solution illustrates the technical possibilities and leads to a thermodynamic design that is supported by theoretical models.

The creation of both projects aims to culminate in the same results, thus complementing the projects with each other, because where one has limitations, the other corrects them, also complementing the research and analysis of what the theory comments, applying it in the simulation.

1. Electrical energy

To begin with, the definition of electric energy will enunciate from a focus in electricity generation plants. "The electrical energy produced by power generation plants is defined as the capacity of an electrical system to perform work. In generation plants, this energy has produced by converting another form of energy, such as mechanical power, hydropower, thermal power, nuclear power, solar power, wind power, or tidal energy.

Electrical energy is transmitted and distributed to consumers through electrical transmission and distribution systems." (Chapman, "Fundamentos de sistemas eléctricos de potencia", cuarta edición, p. 2)

With the growth of society, the demand for electricity increased and it was necessary to build new power plants and distribution networks. During these years, technological advances meant that coal combustion was not the only way to obtain electrical energy, for those years, in distinct parts of the world, the first hydroelectric and wind power plants were developed by the 1920s, electrical energy was already widely used worldwide, thus promoting the development of new sources of energy, these being solar, geothermal, biomass, among others. The first nuclear plant was officially inaugurated in Russia in 1956.

Talking about electricity being a "necessity" today is based on the endless daily activities that would be impossible to perform without electric power. Starting with the most essential such as: cooking, having a shelter, clothing, communication, transportation, medicine.

Nowadays it is unthinkable to live without the comforts that electricity provides us. It is inconceivable to preserve food without the aid of a refrigerator, to build a house without the aid of machinery, and to live in a house without electrical installation.

Nuclear energy

The process of obtaining nuclear energy comes from two processes: fusion and nuclear fission.

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During the fusion process, two light atoms, usually hydrogen and its isotopes (deuterium and tritium). They bind or fuse, as the name implies, resulting in a heavier atom in their nucleus and simultaneously releasing energy upon bonding.

The most practical example of a nuclear fusion is in the sun. In our star, hydrogen nuclei that form helium fuse and release such enormous amounts of energy that they can reach the surface of the earth, and we feel like heat and light.

Two theories have proposed to fuse light nuclei, as it is necessary to have an extremely high amount of energy, to bring the nuclei closer to such small distances that the nucleus's force of attraction is greater than the force of electromagnetic repulsion. One method is to accelerate an "A" particle.

At a speed sufficient for the resulting force to be greater than the repulsion force, Once the desired speed is achieved, the particles 'B' are released and collide with each other, leading to nuclear fusion and, consequently, the release of desired energy.

The other method consists of heating the atoms to gigantic temperatures, to the point of obtaining plasma, in this state of matter, the electrons are free, and the atoms ionized. The problem with this method for fusion lies in the confinement of the plasma to those temperatures. Currently, reactors and vessels capable of withstanding the conditions required by the processes are still under development.

The process of nuclear fission involves supplying an incident neutron to a heavy atom, splitting it into two lighter atoms, resulting in the release of neutrons, gamma rays, and significant amounts of energy.

When the heavy atom receives the neutron, it becomes unstable in its nucleus, which produces a division of the nucleus, resulting in lighter and more stable atoms, in addition, in the reaction neutrons are released that impact other heavy atoms, causing a series of fissions, releasing an effect called chain reaction.

The thermal energy produced by the fission reaction in the vessel of a nuclear reactor is used to generate electricity in a nuclear power plant.

The main part of a nuclear power plant is the reactor, as it houses the nuclear fuel and the systems that conduct fission reactions in a controlled manner, releasing the thermal energy necessary to heat the water and convert it into high-pressure steam. Steam propels a turbine that is connected to a generator. The mechanical power is transformed into electrical energy, which is then transported for commercial use.

2. Software for simulation of thermodynamic processes

In this section a small demonstration of the basic capabilities of two software will be made, the main idea is to show the possibility of designing thermodynamic cycles in these simulators, maintaining a nuclear power plant approach, thanks to these programs, it was possible to simulate this type of generation plant, for easy study and understanding of this type of thermodynamic cycles.

2.1 Importance of simulation software.

Today, the use of technology has increased in countless areas. Simulation is a technique that enables the analysis of any desired system.

The simulation models were created to simulate the behavior of these systems. They are mathematical representations of real systems that use programming tools, taking the form of software running on a computer.

The industry relies on simulation software for several reasons. A fundamental point is the optimization of the design, in engineering the use of simulation software allows you to explore various configurations of a single system, looking for the optimal one.

Following this logic, it is also possible to evaluate the performance of the systems prior to their construction, this has a direct impact on the quality of the result, since it is known in greater detail how the product or process will behave in its different operational stages, all thanks to the prediction made by the software.

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It is impossible to talk about benefits without mentioning the savings that a simulation can provide. That is, costs and time. By allowing a virtual test of ideas and prototypes, choosing in the most suitable simulation for the project, it is possible to reduce development and construction time. By identifying and correcting potential design errors, one can also choose a more suitable material during the simulation.

Another valuable point is safety, because as already said, Simulations can assist in identifying potential failures, possible safety failures, which allows these errors to be addressed before they happen and become potential risks for production, operators or even society.

In summary, simulation software is an essential tool throughout the engineering industry, as it provides an efficient and cost-effective way to design, analyze and optimize a wide range of systems and processes. These constitute an effective instrument within the training and technical certification of personnel who will operate thermoelectric plants. The operating personnel are trained using a simulator, who will acquire the skills and abilities required to solve problems and situations that compromise the operation of a plant in real life, without putting the systems of said plant at risk.

Two thermodynamic cycle simulators were chosen because they were the most suitable for the type of project studied: the Thermoflex for which you have an educational license and the "BWR" or boiling water reactor nuclear plant simulator (BWR NPS).

3. Thermoflex

The main purpose of this software is the design and simulation of thermal systems, it allows analyzing a wide number of variables, from heat transfer, fluids (ranging from coolant of a system to water used as a supply for systems that run on steam), fuel flows, air, among many other analysis tools

Figure 1 shows the main screen of the program, it seeks to generate a friendly and intuitive interface for the user; to be able to simulate anything, it is first required to design a system. Given the wide variety of software libraries, many configurations can be created.

Box 1

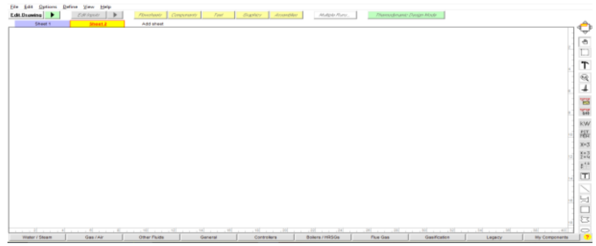

Figure 1
Thermoflex main display
Source: own elaboration

Here are the three most used source types in software (Figure 2) in most systems, water, air/gas, and fuel, respectively.

Box 2

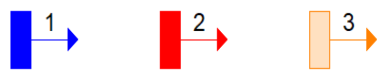

Figure 2
Thermoflex Sources
Source: own elaboration

Simple systems like a water source, a turbine, and a receiver can be created to close the circuit., by doing this, the software allows you to edit the characteristics of each element placed in the design (Figure 3).

Box 3

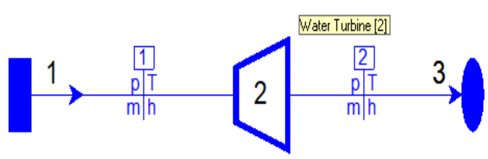

Figure 3
Thermoflex Water turbine
Source: own elaboration

The first suggested input is the environmental conditions, altitude, temperature, humidity, etc. (Figure 4).

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Cortes-García, Alicia, Valencia-García Alejandro Cesar, Rodríguez-Miranda, Gregorio and Mendoza-Hernández, Guillermo. [2024]. Virtual reality forklift simulator - VRFS. ECORFAN-Journal Democratic Republic of Congo. 10[18]1-7: e11018107.
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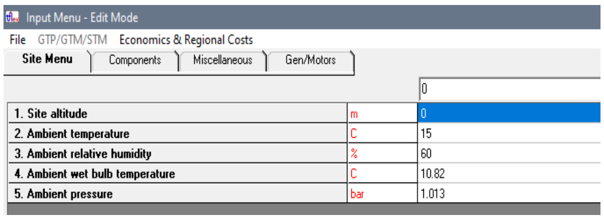
Box 4



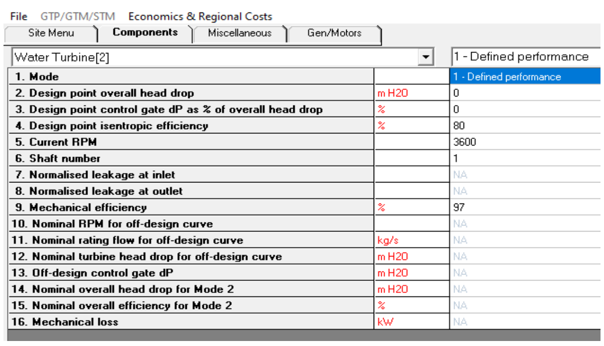
Input Menu - Edit Mode
File GTP/GTM/STM Economics & Regional Costs
Site Menu | Components | Miscellaneous | Gen/Motors

		0
1. Site altitude	m	0
2. Ambient temperature	C	15
3. Ambient relative humidity	%	60
4. Ambient wet bulb temperature	C	10.82
5. Ambient pressure	bar	1.013

Figure 4
Thermoflex menu
Source: own elaboration

It is also possible to edit the values presented, in this case for the water turbine, as well as for the water supply. (Figures 5 and 6).

Box 5

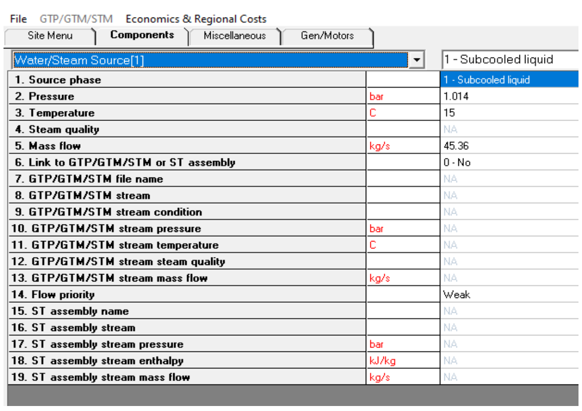


File GTP/GTM/STM Economics & Regional Costs
Site Menu | Components | Miscellaneous | Gen/Motors

Water Turbine[2]		1 - Defined performance
1. Mode		1 - Defined performance
2. Design point overall head drop	m H20	0
3. Design point control gate dP as % of overall head drop	%	0
4. Design point isentropic efficiency	%	80
5. Current RPM		3600
6. Shaft number		1
7. Normalised leakage at inlet		NA
8. Normalised leakage at outlet		NA
9. Mechanical efficiency	%	97
10. Nominal RPM for off-design curve		NA
11. Nominal rating flow for off-design curve	kg/s	NA
12. Nominal turbine head drop for off-design curve	m H20	NA
13. Off-design control gate dP	m H20	NA
14. Nominal overall head drop for Mode 2	m H20	NA
15. Nominal overall efficiency for Mode 2	%	NA
16. Mechanical loss	kW	NA

Figure 5
Thermoflex Component Edition (Turbine)
Source: own elaboration

Box 6



File GTP/GTM/STM Economics & Regional Costs
Site Menu | Components | Miscellaneous | Gen/Motors

Water/Steam Source[1]		1 - Subcooled liquid
1. Source phase		1 - Subcooled liquid
2. Pressure	bar	1.014
3. Temperature	C	15
4. Steam quality		NA
5. Mass flow	kg/s	45.36
6. Link to GTP/GTM/STM or ST assembly		0 - No
7. GTP/GTM/STM file name		NA
8. GTP/GTM/STM stream		NA
9. GTP/GTM/STM stream condition		NA
10. GTP/GTM/STM stream pressure	bar	NA
11. GTP/GTM/STM stream temperature	C	NA
12. GTP/GTM/STM stream steam quality		NA
13. GTP/GTM/STM stream mass flow	kg/s	NA
14. Flow priority		Weak
15. ST assembly name		NA
16. ST assembly stream		NA
17. ST assembly stream pressure	bar	NA
18. ST assembly stream enthalpy	kJ/kg	NA
19. ST assembly stream mass flow	kg/s	NA

Figure 6
Thermoflex Component Editing (suply)
Source: own elaboration

In this scenario, we have a fuel-fed heater that has air inlets and outlets, as well as a water supply. From this heater, steam is obtained. Figure 7.

Box 7

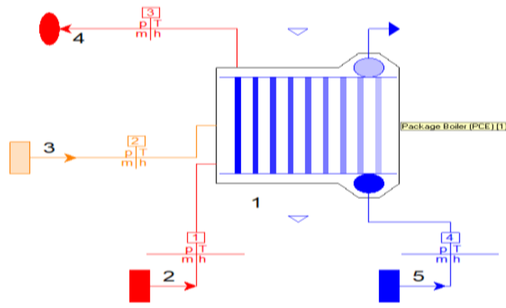


Figure 7
Thermoflex Package boiler
Source: own elaboration

To the heater shown above, components were added to complete the system, to the outlet of the heater, (steam) we have connected with the identifier no. 6 is the turbine, later, with no. 7, is the condenser, to this arrives the steam outlet of the turbine and as a refrigerant, the software offers a source called "brine", which can be translated as brine, or saline water, simulates a system that is fed with seawater.

At the outlet of the condenser water is obtained which will be directed to a drain, it could well be reintegrated into the system to be used in the entrance to the heater, however, it requires more components that would make the system more complex and therefore the introduction to it.

Box 8

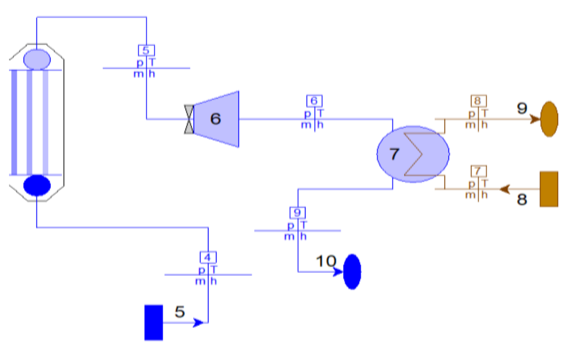


Figure 8
Thermoflex Steam System
Source: own elaboration

With a simple and demonstration design, you have the option to edit the entries to your liking, on this occasion, The decision was made to operate with the values suggested by the software, it should be noted that these values are exceedingly small.

This image (figure 9) shows the system operating without failures and continuously, that is, the simulation is running. Due to the values chosen, the generator (placed in the upper right corner) tells us that there is no power generation.

Box 9

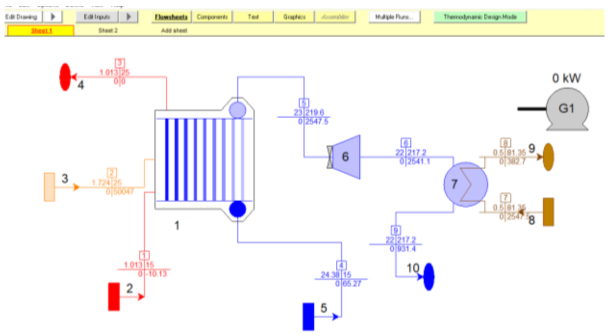


Figure 9
Thermoflex Rankine cycle
Source: own elaboration

However, when we analyze the generator further (figure 10), we can see that, it there is an exceedingly small power generation, as a result of the values that were entered into the components.

Box 10

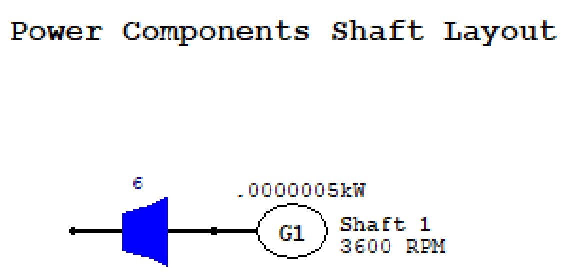


Figure 10
Thermoflex Generator
Source: own elaboration

3.1. Nuclear plant simulation

This section presents the simulation of a nuclear plant operating with an approximate capacity of six hundred megawatts.

It had simulated, and the result was presented in the following diagram supported by theoretical designs and with the possibilities that the software provides, then it will be broken down component by component, talking a little about its function in the system (Figure 11).

Box 11

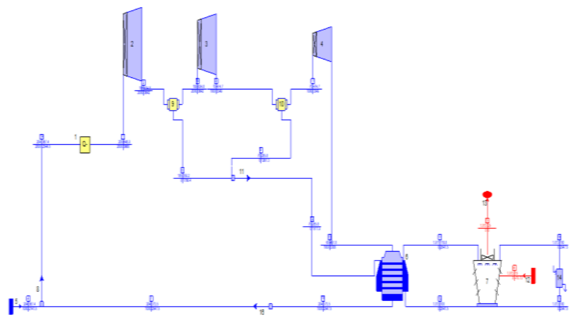


Figure 11
Thermoflex Simulation overview
Source: own elaboration

The software does not have the capacity to implement a nuclear reactor, the way to solve this problem is to use a "heat adder" or heater (figure 12), this component does what its name indicates, and basically it was placed there to simulate the process that takes place inside the reactor vessel, because in the end, the temperature of the steam at the outlet is higher than the one that enters.

Box 12

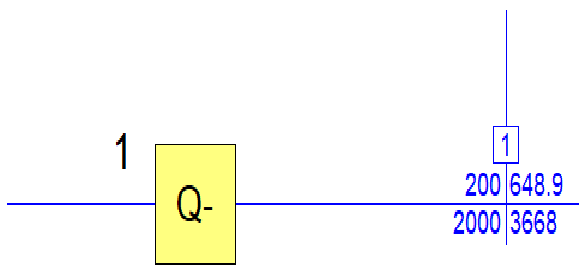


Figure 12
Thermoflex heat adder
Source: own elaboration

Now it is time to design two turbines 2 and 3. This design employed a configuration of three turbines that utilize the same steam line.

Box 13

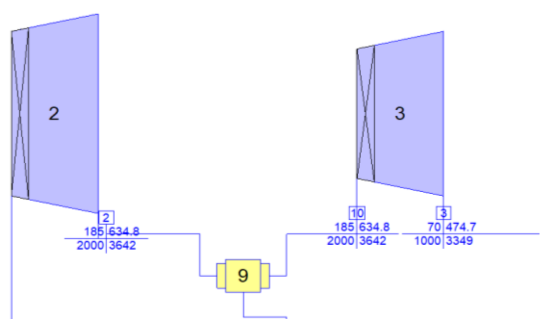


Figure 13
Thermoflex Turbine 2 & 3
Source own elaboration

The configuration of the first turbine or "turbine 2"(figure 14), the pressure point was created to be comparable to the one that is directly from the heater. this being two hundred bars.

Box 14

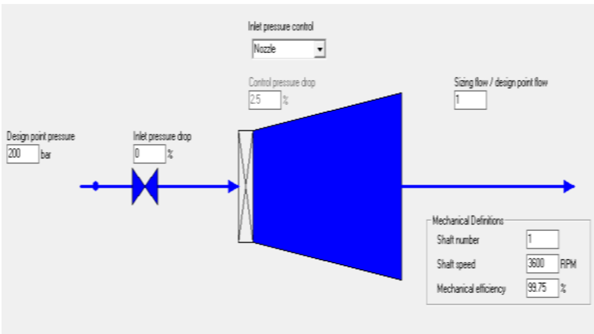


Figure 14
Thermoflex turbine 2
Source own elaboration

The same idea was used to design 'turbine 3' with a lower pressure point than the previous turbine. following a logical sequence of a real process with pressure losses. Figure 15.

Box 15

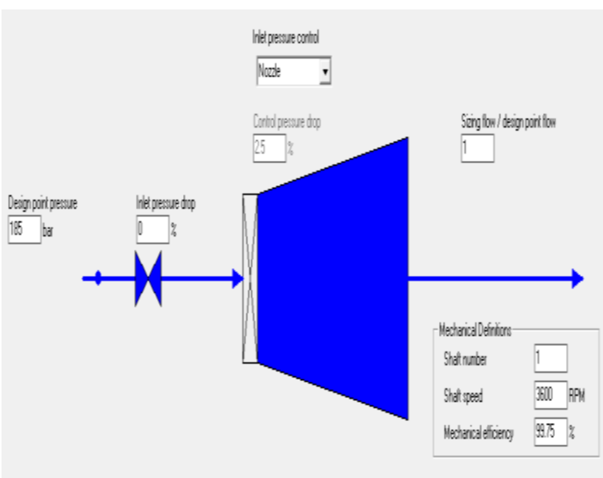


Figure 15
Thermoflex turbine 3
Source own elaboration

In figure 13, component nine appears among the turbines, this is a "moisture separator" or moisture separator, it complies with what its name suggests, It was placed to be a 'filter' and maintain the highest possible quality of the steam that enters the turbine.

Between "turbine 3" and "turbine 4" another moisture separator was placed that fulfills the same function as the previous one. Figure 16.

Box 16

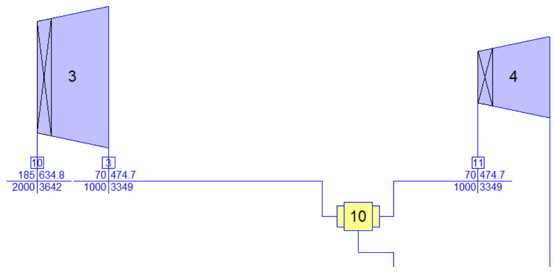


Figure 16
Thermoflex Turbine 3 and 4
Source own elaboration

The design of this turbine (figure 17) is established for a lower pressure than the previous ones, having a design point for 70 bar, thus completing a set of 2 high pressure turbines and one low pressure turbine.

Box 17

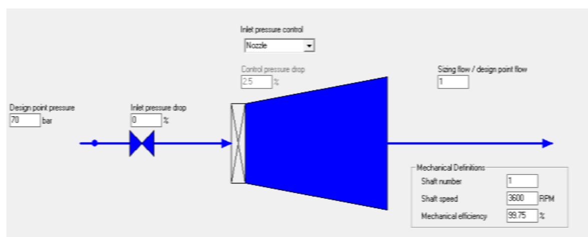


Figure 17
Thermoflex turbine 4
Source own elaboration

Figure 18 shows the configuration chosen to send the water and steam outputs expelled by the turbines, combining them to deliver them to the condenser.

Box 18

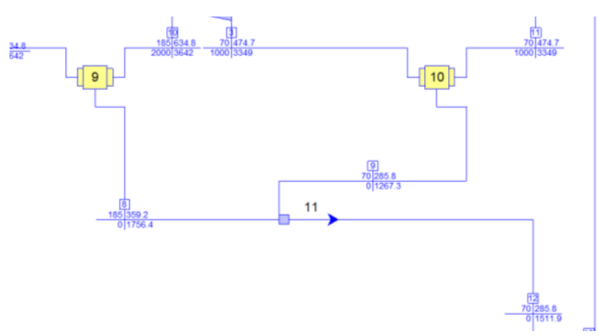


Figure 18
Thermoflex Lines routed to the condenser
Source: own elaboration

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Cortes-García, Alicia, Valencia-García Alejandro Cesar, Rodríguez-Miranda, Gregorio and Mendoza-Hernández, Guillermo. [2024]. Virtual reality forklift simulator - VRFS. ECORFAN-Journal Democratic Republic of Congo. 10[18]1-7: e11018107.
https://doi.org/10.35429/EJDRC.2024.10.18.1.7

Figure 19 shows how the steam lines coming from the turbines converge in the condenser to be processed by it.

Box 19

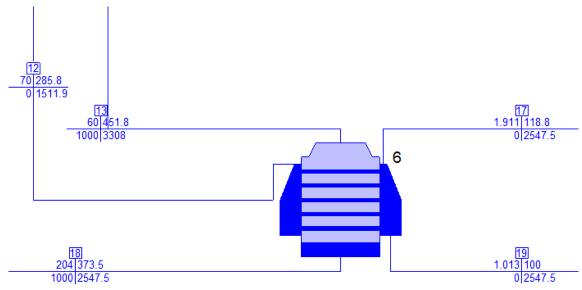

Figure 19
Thermoflex Condenser
Source own elaboration

Figure 20 shows the standard configuration that the software provides, it should be noted that this component has the capacity to receive two different lines of steam, (the one that comes from "turbine 4" and those resulting from the humidity separators) as well as the hot water output and its return with cold water, to later release the condensed liquid back into the system.

Box 20

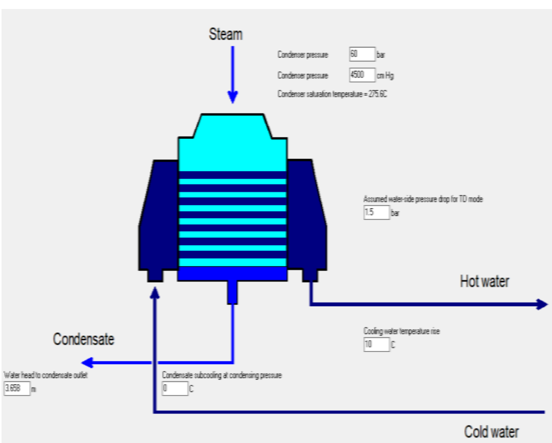

Figure 20
Thermoflex Condenser Design
Source own elaboration

The hot water outlet from the condenser is directed directly to an air-supported cooling tower, represented by inlets and outlets 13 and 14. Figure 21.

Box 21

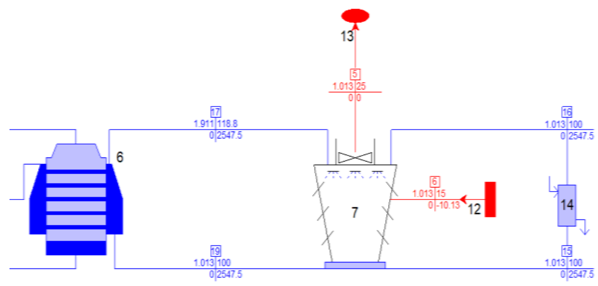

Figure 21
Thermoflex Cooling tower
Source own elaboration

A standard configuration was chosen for the wet cooling tower, and the chilly water resulting from this is redirected to the condenser.

The selected cooling tower requires an external water source as shown in the figure below.

Box 22

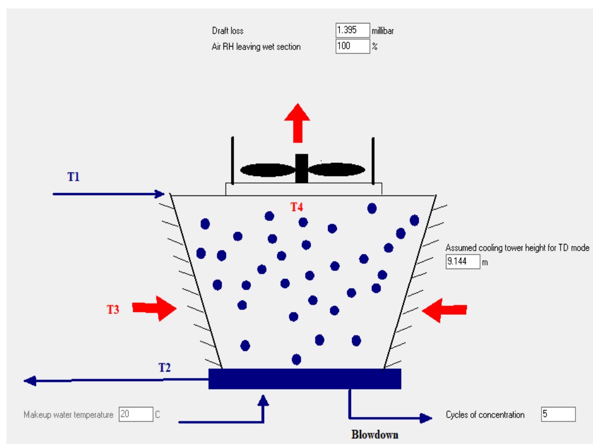

Figure 22
Thermoflex Cooling tower configuration
Source own elaboration

"Makeup water" and "blowdown" can translate as "make-up water" and "drain" respectively. These functions are fulfilled by component 14, shown in Figure 21.

Once the condensed liquid has been obtained, it is directed to what we initially consider to be the substitute of the reactor, before placing a new source of steam, supporting the temperature and pressure of the system to promote greater efficiency in the turbines, and therefore a greater amount of electrical energy generated. The values given to the steam source are listed below.

Box 23

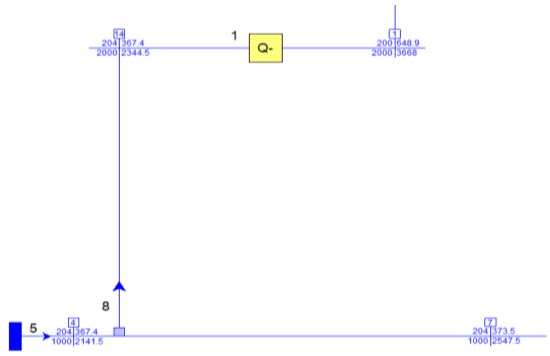

Figure 23
Thermoflex Back to heat adder
Source own elaboration

Box 24

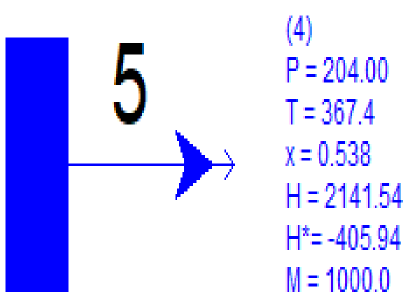

Figure 24
Thermoflex Steam source
Source own elaboration

Once the system design is completed, the software allows a simulation to be run and within the tools of this, it finds the possibility of implementing an electrical generator to the system, which analyzes the values chosen in the design of the components, Allowing us to obtain a result for statistical or processing purposes.

Box 25

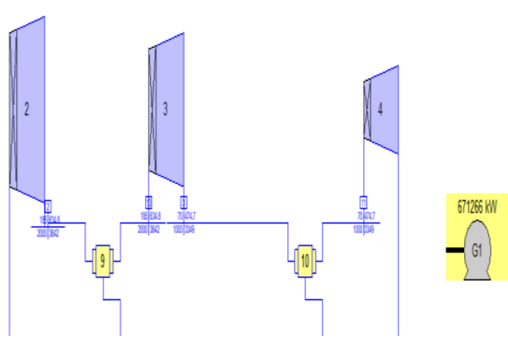

Figure 25
Thermoflex Generator
Source own elaboration

As already mentioned, in this exercise, we seek to exemplify a nuclear plant, in this simulation a generation of 671,266KW was obtained (figure 26), this would be within the average of a conventional nuclear plant, which shows us that the design is optimal to be executed in the proposed simulation.

Box 26

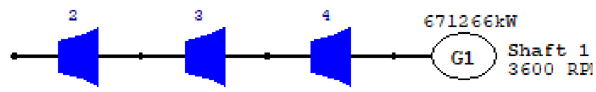

Figure 26
Thermoflex Turbine shaft and generator
Source own elaboration

4. BWR NPS

The "BWR" or boiling water reactor. Nuclear Plant Simulator (NPS). In short, the control panel of a nuclear power plant, in which we are allowed to manipulate the nuclear power plant at will, the area where the greatest emphasis is placed for the program is on the reactor vessel, because when manipulating the control rods, the chain reaction increases or decreases, depending on the case.

Here is the main panel with which the software allows us to interact, for the demonstration of one of the functions of the program the reactor will be heated in a controlled manner, gradually increasing the desired values Figure 27.

Box 27

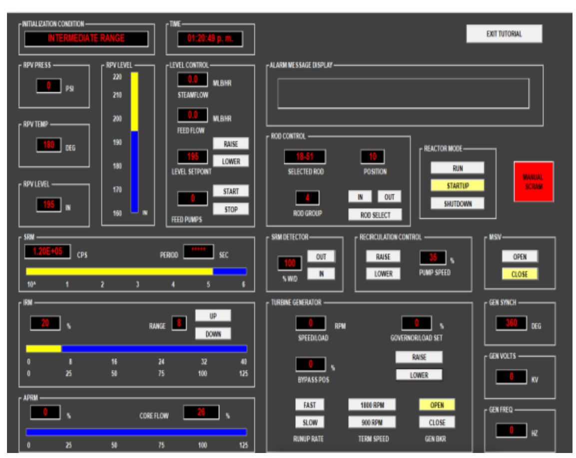

Figure 27
NPS Control Panel
Source own elaboration

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For this demonstration we will focus on these areas of the panel, the values that interest us on this occasion are the following:

Box 28

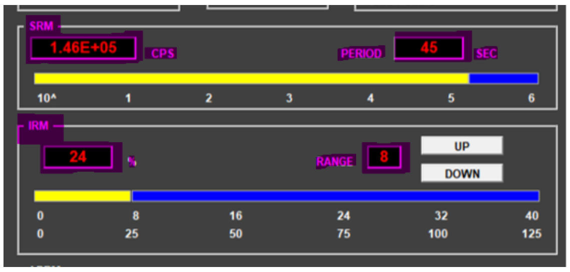

Figure 28

NPS Units of reaction

Source own elaboration

The "SRM" sourse range monitor. This indicator shows the neutron population, the unit expressed is counts per second "CPS", this system indicates ranges from 1 to 1 million, in this order, 100,000 CPS are expressed as 1.0E+05.

The "PERIOD" refers to how fast the power in the reactor is changing. A period of 100 seconds means that the power is increasing in a range of approximately 2.72% every 100 seconds, in the same way if the indicator shows -100 seconds, it means that the power is decreasing in the same range.

The "MRI" intermediate range monitor. This indicator shows the relative neutron population, that is, the percentage of the neutron capacity that the reactor can accommodate, this is It shows in two scales, from 0 to 40% and from 0 to 125%, depending on the scale that best suits you. The "RANGE" is expressed from 1 to 10 and is used to increase or decrease the range of the MRI, understood as the speeds to a car.

To increase power in the plant, the "ROD CONTROL" panel is interacted with.

Box 29

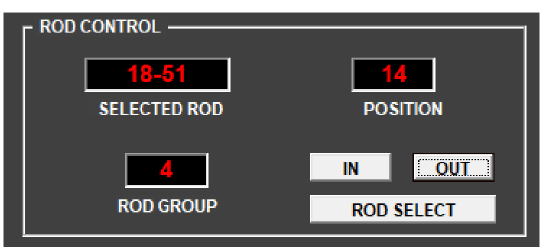

Figure 29

NPS Bar Controller

Source own elaboration

Each group of bars has positioning limits, in this case, for group 4, the effective limit is position 16, when you click on the "out" button, the bar is removed, thus generating an increase in the fission reaction. Figure 30

To select the correct bar to remove or enter, it helps to visit the map. Figure 31.

Box 30

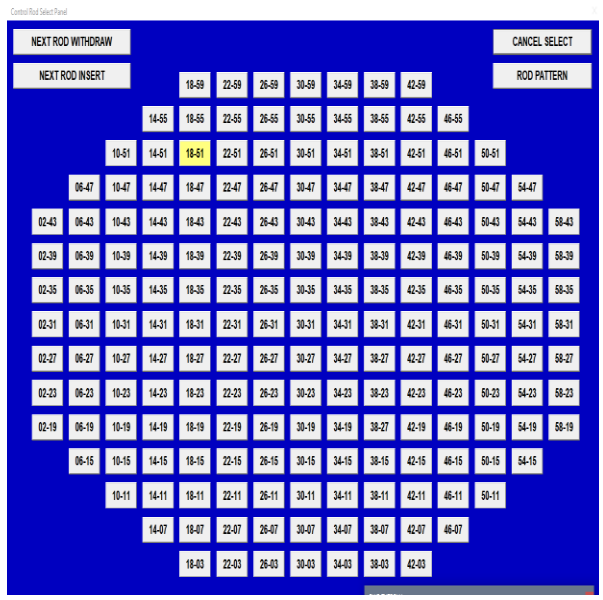

Figure 30

NPS Control bar selection

Source own elaboration

On this screen, it is possible to select the bar and then manipulate it. In this scenario, we are on bar 18-51, because they belong to group 4, they have as an effective limit to enter up to position 6, but to not be at the limit, they are usually in position 8. And they have as an effective limit, the possibility of folding to position 16.

The software provides us with this map, as we saw previously, we were at bar 18-51, which, when reaching its limit, but not the desired power levels, it is required to remove the next bar, in this case, bar 34-51 and then those highlighted in green, as they are in the standard position of their group.

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Box 31

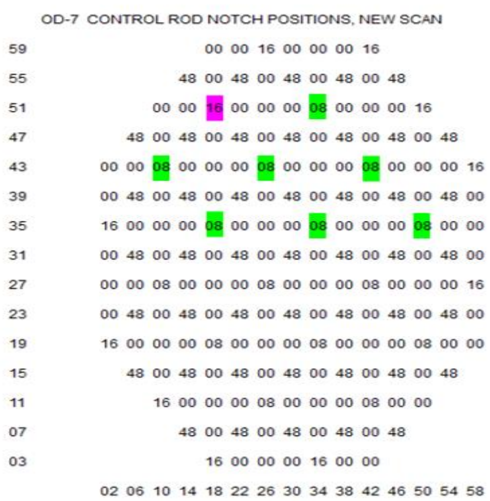

Figure 31
NPS Control bar map

Source own elaboration

By making the correct movements with the control rods (the correct rods at the ideal speed and times) we can increase the period, by reducing the time, we increase the neutron reaction rate, once the rods were removed, the period was reduced to 29 seconds and the SRM went from 1.46E+05 to 8.75E+05. The IRM also increases during the process, thus the range increased from 8 to 9 (this process is done manually when the IRM bar approaches its limit). Figure 32.

Box 32

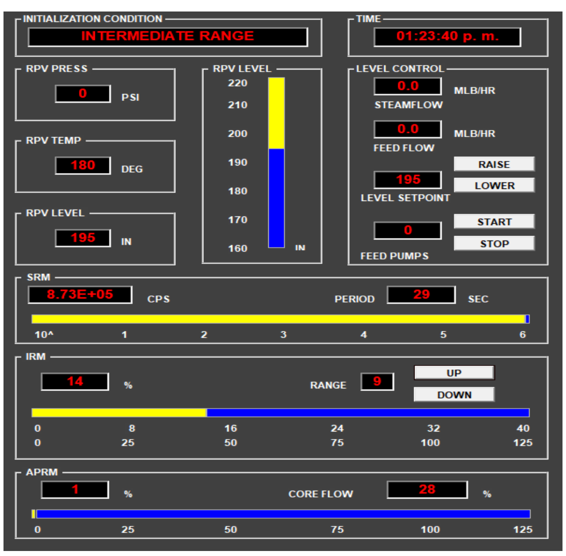

Figure 32
NPS Result of the reactor heating

Source own elaboration

5. Simulation with BWR NPS

In the previous section we talked a little about this software, with which we can represent the dashboard of a nuclear plant, it has a wide range of simulation tools, from a critical condition of the reactor to the start-up, which would give birth from the heating of the rector to the start-up of the turbine.

The system's turbine will be put into operation during this simulation exercise, seeking to match the power generation with the simulation proposed in Thermoflex.

At the beginning of the simulation, we find that the simulator finds an MRI (relative percentage of the neutron population inside the vessel) of 10%, which leads to the heating of the system. Figure 33.

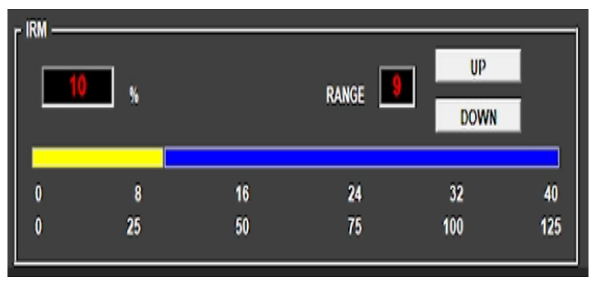

Figure 33
NPS Initial MRI

Source own elaboration

As shown in the previous chapter, the control rods must be removed to increase the chain reaction.

The neutron population needs to be increased enough for the "pos bypass" (representing the position of the main turbine's shut-off valve) to open. Figure 34.

Box 34

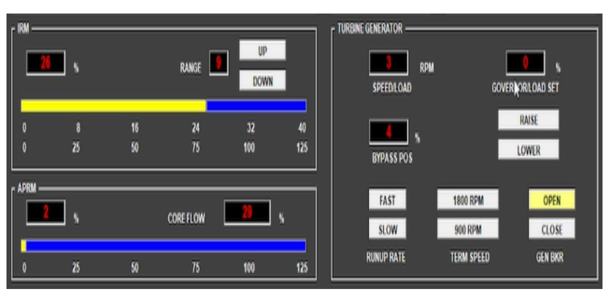

Figure 34
NPS Bypass open

Source own elaboration

After increasing the MRI to approximately 26%, the valve is opened to 4%, then bars should continue to be removed until the POS bypass is in a range of 30% to 35%.

Box 35

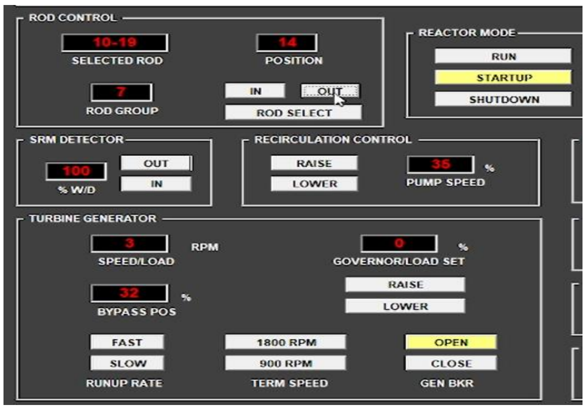

Figure 35
NPS Bypass 32%

Source own elaboration

After the valve opening has been reached, the reactor mode must be set to 'RUN'.

Once the generator mode is changed, it is time to start the turbine, this starts slow and at low revs.

That is, after putting the reactor in "RUN" mode, the acceleration is selected at "SLOW" and the speed at "900 RPM" (Figure 36).

Box 36

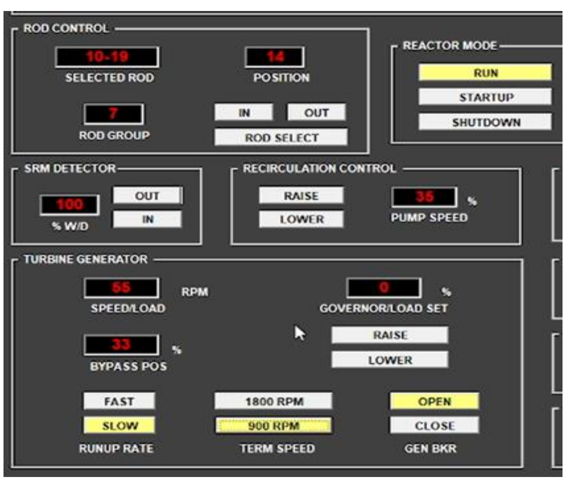

Figure 36
NPS 900RPM turbina

Source own elaboration

Once these steps are done, the “speed/load” marker starts to increase.

Box 37

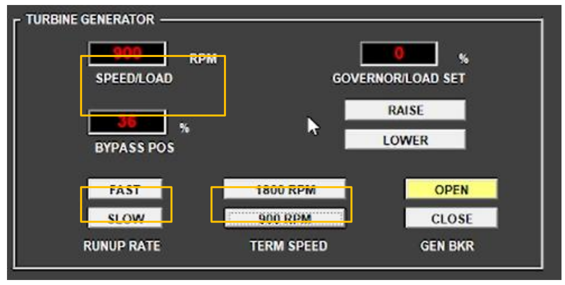

Figure 37
NPS 900RPM turbine

Source own elaboration

Again, after these steps, the revolutions continue to increase, and once 1800 RPM is reached, the "GEN SYNCH" (shows the angle of rotation between the generator and the electrical distribution system and the synchronization between them) begins to rotate in a negative direction figure 38,

Box 38

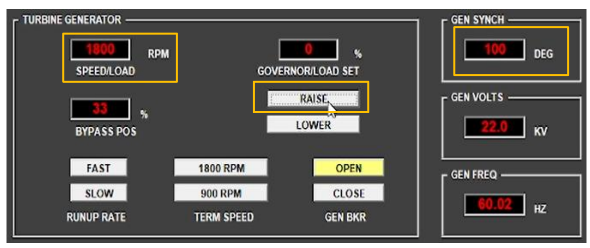

Figure 38
NPS GEN SYNCH

Source own elaboration

After clicking on the "RAISE" button, the rotation speed of the SYNCH gene begins to decrease, the rotation must be reversed before you can continue with this.

Once the rotation has been reversed, the generator switch must be closed when the marker is 360°. Figure 39.

Box 39

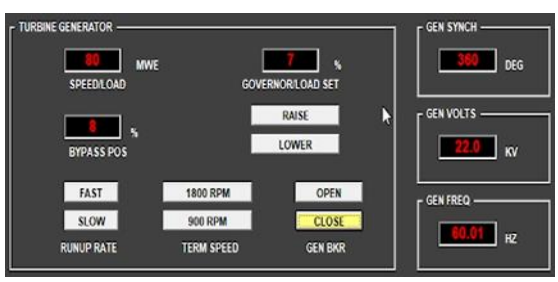

Figure 39
NPS GEN BKR

Source own elaboration

Once the generator is synchronized, all that remains is to increase the power of the plant, increase the "governor/load set", allow to increase the capacity of the generator and in turn, close the "BYPASS POS" valve which at the same time gives rise to continue extracting the control rods.

The process of increasing electricity generation consists of removing the control rods in the order dictated by the map of the rods, each time the steam generated exceeds the capacity of the turbine, the capacity of the generator has to be increased, which closes the valve and allows the process to continue.

To maintain the increase in power in a controlled manner, it is necessary to remove the bars one by one and point by point.

As mentioned at the beginning of this project, the idea is to generate the same amount of energy as in the Thermoflex project.

Here it is shown as the final generation of the project 671MWE (figure 40), exact value to which the project shown in Thermoflex yields, as shown, the capacity of the generator is at 60%, taking this into account, we can understand that this software has the capacity to produce more electrical energy, however, given the limitations that are dealt with in Thermoflex.

The energy it generates can be considered as a maximum value given the possible values and the proposed design, however, 60% of the plant's capacity helps to maintain better control of it.

Box 40

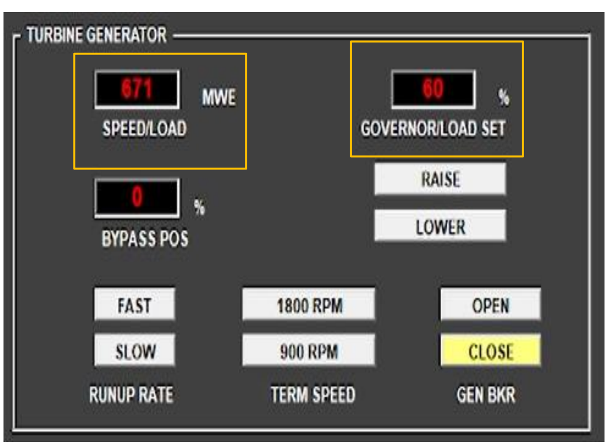

Figure 40
NPS Final generation

Source own elaboration

Conclusions

The study has analyzed and explored the various methods of power generation in great detail, it was enriching to study at least superficially the way in which electricity generation plants operate.

Thanks to the fact that the main focus of this project is based on nuclear energy, an entire chapter was dedicated to the analysis of this topic, seeking understanding from the most basic topic, starting with the physicochemical structure of the atom and its reactions, it was nourishing for the research and personally to understand the fundamental concepts to understand the later topics, that is, the operation of a nuclear power plant.

Arriving at the study of the nuclear power plant led to various branches, since delving into the study of nuclear reactions, approached the domain of quantum mechanics, this becomes interesting and perhaps studying future projects., but it was beyond the scope of this project.

As a result of studying the theoretical concepts that encompass a nuclear power plant, it was possible to design a project with the intention of complementing the research., the intention was to complement the research, giving it a virtual view, promoting the understanding of the subject.

Coming to the software, specifically Thermoflex, it was complicated to understand the program, since the existence of guides or manuals is almost nil, even more so for this specific project, since the software itself is not designed to house a nuclear power plant, due to these limitations and added to the fact that an academic version of the program was used. pure simulation, only in Thermoflex, was incomplete.

Due to this scenario, BWR NPS was reached, this simulator helped to nourish the general project, since a panel in which to control all the elements that control the plant was what the project needed to complete the empty space generated by Thermoflex.

This article allows the understanding for a particular case, applicable to different projects promoted by Thermoflex, because as already mentioned, there are no guides or tutorials in Spanish and those that exist in other languages are not very varied.

For future research, the field of quantum mechanics was remarkably interesting and, above all, broad for exploration, in addition to the specialization in the proposed software, or one that has a greater scope in terms of the elements that they can host.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Each researcher developed the article together.

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Abbreviations

BWR	Boiling Water Reactor
GEN BKR	Generator switch
NPS	Nuclear Plant Simulator
RPM	Revolution per minute
SRM	sourse range monitor

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Article

Virtual reality forklift simulator - VRFS

Simulador de montacargas en realidad virtual - SMRV

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Abstract
This paper presents the development of a virtual reality (VR) forklift simulator by a team at the Universidad Tecnológica de San Juan del Río. Using Eric Ries' Lean Startup methodology, a forklift model was designed based on a pre-existing template and adapted to meet customer needs. The simulator allows users to control all forklift functions, manipulate loads with the forks, and explore a virtual warehouse environment. Functional tests were conducted with the collaboration of teachers and students, demonstrating the effectiveness and realism of the simulator. This innovative approach to training offers a safe and practical environment for pre-practice learning in reality, promoting the development of forklift handling skills. With the use of cutting-edge technology such as Unreal Engine, this simulator represents a valuable tool for training in various industrial sectors.

Virtual Reality, Forklift simulator, Unreal Engine, Blueprint

Resumen

Este artículo describe el desarrollo de un simulador de montacargas en realidad virtual, llevado a cabo por un equipo de la Universidad Tecnológica de San Juan del Río. Utilizando la metodología Lean Startup de Eric Ries, se diseñó un modelo de montacargas basado en una plantilla preexistente, adaptado para satisfacer las necesidades del cliente. El simulador permite controlar todas las funciones del montacargas, manipular cargas con las horquillas y explorar un entorno virtual de almacén. Se realizaron pruebas funcionales con la colaboración de profesores y estudiantes, demostrando la efectividad y realismo del simulador. Este enfoque innovador de entrenamiento proporciona un entorno seguro y práctico para el aprendizaje previo a la práctica en el mundo real, promoviendo el desarrollo de habilidades en el manejo de montacargas. Con el uso de tecnología de vanguardia como Unreal Engine, este simulador representa una herramienta valiosa para la capacitación en diversos sectores industriales.Words

Reality virtual, simulator simulator, unrealEngine, Blueprint

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Introduction

Virtual reality (VR) technology creates a fully immersive, computer created sensory experience that can be used for entertainment, education and training. This technology transports users to three-dimensional virtual environments, where they can interact with objects and scenarios in an almost realistic manner, opening a world of possibilities for the creation of immersive and educational experiences (Franchi, 1994).

Virtual reality (VR) simulators have become a powerful tool for training people in tasks that would otherwise be costly or dangerous to replicate in the real world. They allow users to immerse themselves in highly realistic simulated environments, where they can practice and hone specific skills without taking risks or incurring the high costs associated with traditional training.(Schofield, 2012)

Virtual reality simulators are an effective tool for measuring performance and differentiating learner skill levels, potentially improving the skills, efficiency, and performance of personnel in training. (Sikder, Tuwairqi, Al- Kahtani, Myers, & Banerjee, 2013)

For the development of the project the Unreaal Engine was used, according to Epic Games, is a video game engine developed by Epic Games, known for its power and versatility in the creation of games and interactive multimediacontent. It has been used in a wide range ofprojects, from high-end video games to architectural simulations and film productions. (Games, n.d.)

The machinery that the project is intended to simulate is a forklift. A forklift is a machine capable of lifting heavy weights, similar to a vehicle with two forks that can be slid under the weights and lifted into the air for movement.

This equipment is widely used in warehouses, factories, and other industrial settings to transport and stack materials efficiently and safely.(Jain, Shah, Sunasara, Shirgaonkar, & Jagtap, 2020).

This article focuses on the development of a forklift simulator in virtual reality, using unreal engine 5.

This initiative not only seeks to modernize the loading and unloading processes, but also represents a significant step towards the adoption of Industry 5.0, an industrial revolution that integrates artificial intelligence, advanced automation and interconnection of systems. (Sikder, Tuwairqi, Al-Kahtani, Myers, & Banerjee, 2013).

Problem

Due to the various incidents that may occur in manufacturing industry facilities, in addition to different situations that arise in the handling of heavy loads including spaces that are not authorized for all people. It is intended to develop a virtual environment, to help operators who do not know the handling and constant danger that is maneuvering with this type ofmachinery, have an immersive experience, toeffectively eliminate risks.

Justification

The implementation of forklift simulators in the manufacturing industry improves safety and efficiency in operations.warehouse. They provide a safe environment for operators to acquire skills without risk. The preventive approach seeks to reduce workplace accidents and promote safe practices.

From an economic point of view, the implementation of simulators is a strategic investment, reducing costs associated with traditional training, such as the use of real equipment and the risk of accidents. By avoiding accidents and improving operating practices, costs related to damage, product loss and medical expenses are minimized.

Methodology

The Lean Startup method, developed by Eric Ries, is a startup management model whose objective is the growth and scaling of innovative businesses in uncertain, complex and changing contexts.

Eric Ries' Lean Startup methodology pursues the continuous increase of value throughout the product development process. Key to this is the elimination of unnecessary practices and customer feedback throughout the product development stage.

This methodology was applied with the help of professors and people related to the industrial sector on which the simulator is focused. Each Our customer, this forklift is based on a real, simply manufactured forklift.

Development

The forklift model used is a pre-existing template, the model was modified at our convenience and features were added to meet the needs of our customer, this forklift is based on a real, simply manufactured forklift.

Box 1

Figure 1
Forklift model

In addition, during the development of the project used a Logitech g923 steering wheel, which was mapped as follows in order to be able to use the 3d model. Although it is not necessary to have one of these to make use of the simulator since another input method is the standard computer keyboard of the requirements and functions were tested by the developers and people related to the industrial sector to guarantee the simulator's performance

Box 1

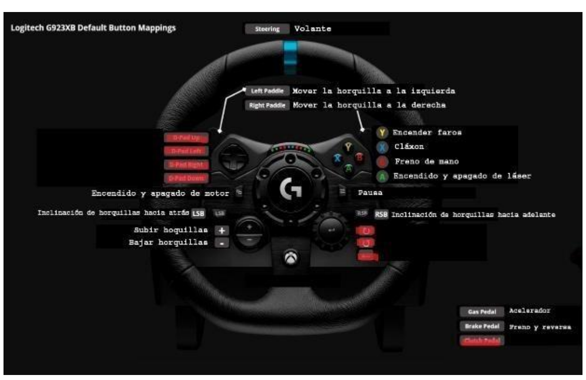

Figure 2
Flywheel mapping

Box 3

Figure 3
Keyboard mapping 1

Box 4

Figure 4
Keyboard mapping 2

Box 5

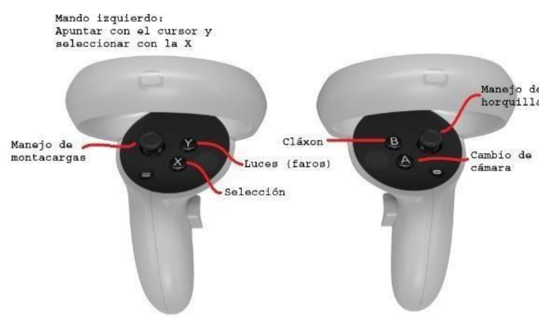

Figure 5
Command mapping

Blueprints

Blueprints in Unreal Engine are a visual programming system that allows developers to create game logic and interactive behaviors without writing code. Using a drag- and-drop approach, users can connect graphical nodes to define the functionality of their games or applications. In Romero's words, "Blueprints in Unreal Engine are a visual scripting interface that allows designers anddevelopers to create interactive content without traditionalprogramming" (Romero & Romero, 2019).

Although the language Unreal Engine uses is C++, we don't touch the code at all, the blueprints are what we modify, merge and parse. As an example of operation, we have a function added by the development team that involves the visualization of the forklift safety laser lights, we can observe (figure 1) how the input event triggers a flip flop that gives visibility or removes the visibility of the safety lights in this case mentioned as network 1,2 and 3.

Box 6

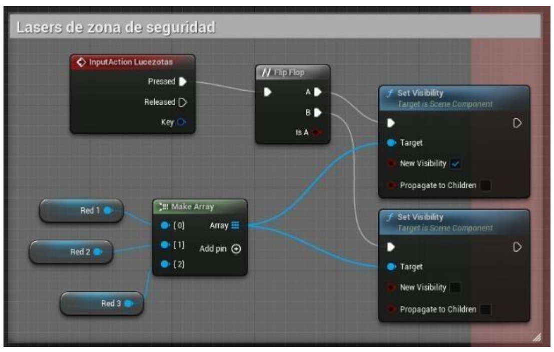

Figure 6
Blueprint of safety lights

When the function input button is pressed, in this case the A key on the Logitech steering wheel, the safety laser lights are visible and can be used in the environment.

Box 7

Figure 7
Safety lights activated

His is how all the features of the simulator, each level, model and function, is composed of logically communicated nodes, like a flowchart.

In the following image we can see the blueprint of a complete level, which includes the function described above.

Box 8

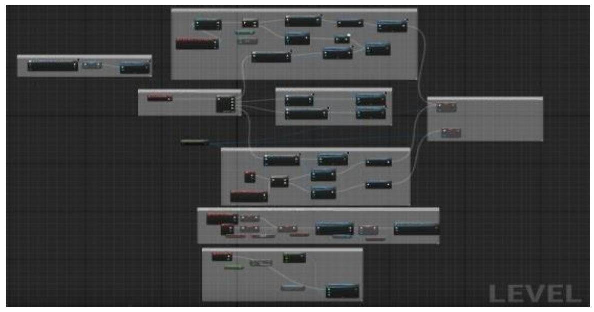

Figure 8
Bluepirnt level

esults

A total of 4 levels were developed for staff training, as described below.

Tutorial: It consists of learning how to operate the forklift, raise and lower the mast, it is basically learning the operation from scratch, coins are collected in a specific course, points are added and at the end we must take the coins to a specific place to credit or pass thelevel.

Box 9

Figure 9
Blueprint of safety lights

Level 1: A level with a low difficulty, consisting of Take 2 objects from one place to another, they are objects that are in some pallets and must be transported to others, after doing so, we must go to another warehouse to complete the level.

Box 10

Figure 10
Level 1 map

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Level 2: The difficulty in this level begins to increase, 5 objects must be placed on a specific platform, the difficulty in this level begins when the level restarts when colliding, or the same thing happens when throwing an object.

Box 11

Figure 10
Map Level 2

Level 3: Consists of an open world with a sensitive

The level will be reset when the pallets collide or do not fit properly on top of each other. The forklift software was designed to fulfill specific functions, these functions were first requested by Load handling stakeholders and professors and then tested by internal university users, which include students involved in the development of the application who were part of the meetings held with the company in question and also professors who have been in contact with the sector to which the software is directed.

The functions are defined by several objectives that the software tries to fulfill, these essential functionalities for the practical operation of the simulator, these objectives are described and analyzed below:

Controlling a forklift with all its functions

The forklift has a standard driving of the basic components of a front forklift, the natural rotation of the rear tires of the forklift, the ability to accelerate, brake andreverse with the forklift, manipulate the forks of the machinery with the corresponding levers, in the appropriate ranges of movement, turn the lights on and offwith the corresponding buttons, etc. These specifications were tested and approved by the professors in charge of the project.

Handling loads by means of forks to relocate materials

This function was tested hand in hand with game physics. A specific level focused solely on this task was developed and tested with the collaboration of teachers and students.

During the tests, it was confirmed that the simulator allowed to carry out this activity in a realistic and effective way, as, for example, carrying different weights affects the speed and ease of manipulation of the forklift.

Box 12

Figure 12
Load handling

To explore the different areas that make up a warehouse

A complete virtual environment was developed that faithfully represents a warehouse, with different sections and storage areas, such as aisles and overhead shelves.

This environment was tested with the collaboration ofteachers and students, who were able to walk through and explore the different areas interactively. During the tests,it was confirmed that the simulator provided an approximate and realistic representation of a warehouse.

Box 13

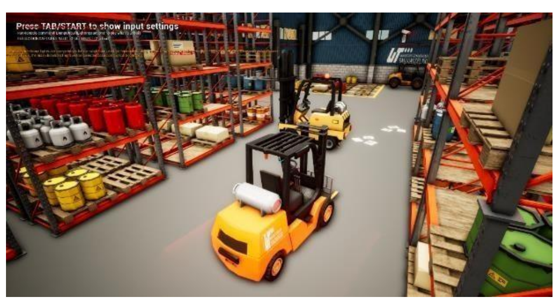

Figure 13
Warehouse environment

Safe operator environment

Within the software were integrated functions on operator safety, such as laser indicators of the forklift safety distance, caution sounds when going in reverse and collision control, the latter was developed a specific level in which the level restarts if the user collides, these aspects were tested by teachers and students involved in the project, who could recognize that these control and safety functions meet the objective of training and basic notions of the operator.

Box 14

Figure 14
Safety lasers and collision warning

Evaluate control through measurements

The simulator has levels, each level teaches a notion of the use of the forklift or expected behaviors of the operator, it was concluded that score indicators should be included to evaluate the operator, each level has a way to evaluate the operator's performance, these functions were tested by teachers and students involved in the project andmeet the intention of evaluating the operator's progress.

Box 15

Figure 15
Level 1 scoreboard

Conclusions

The development of simulators is an area that promises much to the areas of technology and industry, to generate a safe environment for learning prior to practice in reality, I consider it an ideal method for training in any area whether manufacturing or any other.

This project was carried out with the purpose of fulfilling the essential conditions for the operation of the simulator. After developing and testing its functions, we can think that the training in the basic notions of the handling of this machinery is covered by the developed software, this software could be useful in the sector that makes use of this machinery.

The introduction of more advanced functions within the simulator itself, apart from being something expected, I think it would be necessary if we want to develop an integral and complete simulator that teaches not only basic notions but also more complex behaviors and situations that may arise in the industrial environment of the simulator.

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Domotic control by codification of electromyographic signals and network sockets

Control domótico vía codificación de señales electromiograficas y socket de red

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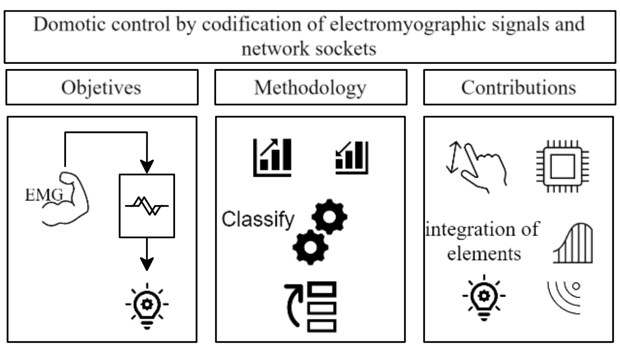
Abstract

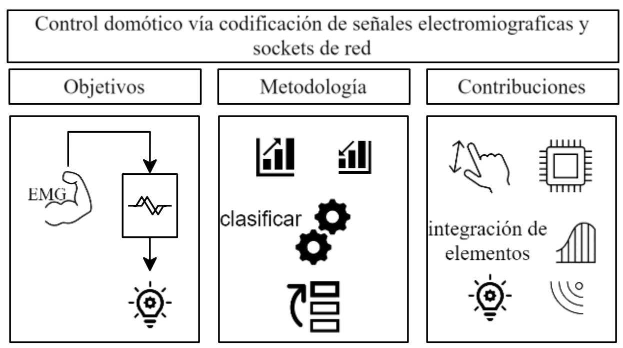
This article presents a system where signals generated by an electromyographic sensor on a person are sent through a client-server network topology. The purpose of these signals is to manipulate home automation devices only with certain arm movements, thus creating a gadget that does not require a keyboard or a touch screen. So that the signal can be interpreted as a control instruction, different patterns of EMG signals were defined that are possible to identify by means of a coefficient evaluation between signals. The use of sockets allows devices to be manipulated on local networks or over the Internet.



Domotic-Control, Electromiography, Socket-Network

Resumen

En este artículo se presenta un sistema donde se envían señales generadas por un sensor electromiografico en una persona a través de una topología de red cliente-servidor. El propósito de estas señales es manipular dispositivos domóticos solo con ciertos movimientos del brazo, creando así un *gadget* que no requiere de un teclado o una pantalla táctil. Para que la señal pueda ser interpretada como instrucción de control, se definen diferentes patrones de señales EMG que son posibles de identificar por medio de un coeficiente de correlación entre señales. El uso de sockets permite que se puedan manipular dispositivos en redes locales o a través de Internet.



Control-Domótico, Electromiografía, Socket-Red

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Introduction

The development of technologies such as the Internet of Things (IoT) has led to the creation of network applications, many of them wireless, which achieve task automation and person-to-machine (P2M) and machine-to-machine (M2M) communication (Nathan et al. 2019). Among these applications are those that operate within home networks, known as Home Area Networks (HAN).

Various sensors have been employed in HAN networks with the goal of minimizing human intervention in performing certain tasks. For example, there are solutions ranging from panic alarms via RFID (Widiantari et al. 2022), automatic light control with presence sensors or cameras (Ngoc et al., 2014), to authentication with biometric sensors (Ramli et al, 2013), among others. These solutions tend to use information derived from human characteristics, such as physical traits or body movements, including muscle movements in the arms.

In this context, it can be noted that human muscles exhibit electrical activity when they contract in response to some stimulation. The study of these variations is known as electromyography (EMG). The use of electromyography has expanded from nerve conduction studies to detect certain diseases to hardware control via muscle movements (Minjie & Honghai, 2020) (Kühn et al 2024) (Vujaklija 2024).

To detect these signals, two types of sensors are used: invasive (inserted into a person’s skin) and non-invasive (electrodes that only require external contact with the skin covering the muscle). For the latter, models and signal processing techniques have been employed to enhance the information received and generate more and new applications in various fields (Marletti, 2004).

The objective of this paper is to define certain EMG signals that can be produced from a person's arm and encode them into control instructions for a home automation system. For this purpose, a hardware prototype was designed to function as a gadget that does not require a keyboard or touchscreen to send instructions. Unlike other solutions, this eliminates the need to use software applications on smart devices such as mobile phones.

This solution considers other users who have communication difficulties, such as with writing or speaking, where touchscreens or speaking systems like Alexa are required.

To identify EMG signals, linear correlation of variables is used to compare the similarity between a generated signal and a predefined signal.

Additionally, the use of a client-server architecture, where communication is established via network sockets, allows for local or Internet-based control.

The work in this paper is organized as follows:

Section 1, "Related Work," presents a brief investigation of other IoT solutions where EMG signals have been used for control and communication. It also mentions some works related to network sockets for client-server solutions with TCP/IP standards.

Section 2, "Development," describes the methodology used, as well as the implementation of hardware and logic system. It includes the interaction of devices through the flow programming software known as Node-RED and the creation of sockets and communication within it.

Section 3 discusses the results obtained in the previous sections, emphasizing those aspects that help to achieve the objectives of this work.

Section 4, "Conclusions," provides a general analysis of the system's operation and mentions potential future work.

Finally, Section 5, "References," lists the bibliography consulted for the development and theoretical foundations of this work.

1 Related Work

Sensors on the human body are becoming increasingly common as sources of information for IoT applications, with desirable characteristics including low energy consumption and wireless connectivity (Harshitha et al., 2018). Among these sensors are those that send EMG-type signals, which have gained significant attention due to their use in fields such as robotics.

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For example, Ibarra-Fuentes and Morales-Sanchez (2022) propose controlling a mobile robot using EMG signals emitted by a commercial armband known as the Myo Armband, which has 8 electrodes and 9- inertial measurements axis with its own processor. As a classification method, the authors apply the K-Nearest Neighbors (KNN) algorithm.

Another example of EMG sensor uses, applied to issues beyond health monitoring is presented by Gu et al. (2019). In this work, the authors represent 26 Morse code symbols through EMG signals from a human arm.

Using statistical techniques such as the mean absolute value, they filter the signals and then employ the Constant False Alarm Rate (CFAR) adaptive algorithm for signal encoding.

In this context, signals from sensors need to be transmitted over a data network, requiring a set of communication protocols such as TCP/IP. TCP/IP standards have been used in various control fields, as described by Juhasova et al. (2017).

Here, the authors described the design of a communication channel cell between processes (sockets) that control robotic arms by evaluating sensed variable conditions and programmed logic.

The security provided by a TCP-based socket has been used in device monitoring solutions in IoT architectures (Nathi & Sutar, 2019). To implement these sockets, graphical flow control tools like Node-RED can be used. This tool has been employed in some works for node communication under the publish/subscribe model, commonly used in IoT with the MQTT protocol (Kodali & Anjum, 2018).

Using each of these previously described tools, this work proposes a communication system based on sockets that can control home automation devices through EMG signals.

2 Development

The first objective is to determine the behavior of EMG signals in a person's arm during natural movements, and then propose different signals for home automation control.

To achieve this, an experimental methodology was employed, where conditions were established, and the type of hardware required for measurements was defined to understand the behavior of the signal under study.

2.1. Behavior of EMG Signals in the Arm

EMG signals from the left flexor carpi radialis (FCR) muscle of 20 individuals (10 men and 10 women) were analyzed, with the characteristics described in Table 1, using the following testing software and hardware.

Box 1

Table 1

Physical Characteristics of Individuals Using the OYMotion Sensor

Age	weight	height
Range [18, 56] Avg 32.65	Range (kg) [60, 90] Avg 72.8	Range (m) [1.6, 1.8] Avg 1.69

Source: Own elaboration

Hardware and Software Used:

- OYMotion EMG Sensor with electrode connector PJ-342, module connector PH2.0-3P, voltage output 0-3.0V, and detection range of +/- 1.5 mV.
- ESP8266MOD Microcontroller, 32-bit CPU 160 MHz, 802.11b/g/n
- Card Manager Module for Arduino Esp8266, version 3.0.2
- Adafruit ESP8266, version 1.1.2
- Arduino IDE Development Software, version 1.8.19

2.1.1 Tests Conducted

The OYMotion sensor features an elastic band capable of securing the electrodes on each person's flexor muscle. Once the sensor is in place, each person performed the following actions to define three types of signals:

Rest: Arm stationary to avoid generating any tension in the muscle.

Normal Movements: Lifting and lowering the arm, moving the fingers, lifting an object with the hand, writing.

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Control: Clenching the fist for one second with maximum force and repeating this action 3 times with one-second intervals.

The aim of these three actions is to identify if there are significant changes between the EMG signals, considering that the *Control* signal (point c) involves intentional movement.

To read the values of each EMG signal from these movements, a code was implemented using the Arduino IDE tool with the mentioned libraries and modules. For visualizing samples of these signals, a moving average filter with a window of 10 samples was implemented in the same code. The formula is given in equation [1].

$$\dot{X} = \frac{1}{w} \sum_{k=1}^{w} X_k \quad [1]$$

Where:

$\dot{X}$ is the average value of w samples of EMG signals.

W: is the number of samples to average.

This procedure aimed to smooth the obtained signal by removing noise that may appear with maximum and minimum values. The average behavior of a Rest-type signal is shown in Figure 1. It can be observed that the EMG signal exhibits a uniform behavior, with small amplitude variations (+/- 2 mV). In this figure, it was necessary to reduce the scale on the y-axis to appreciate these variations; otherwise, the signal would appear as a continuous line, as described in the following case.

Box 2

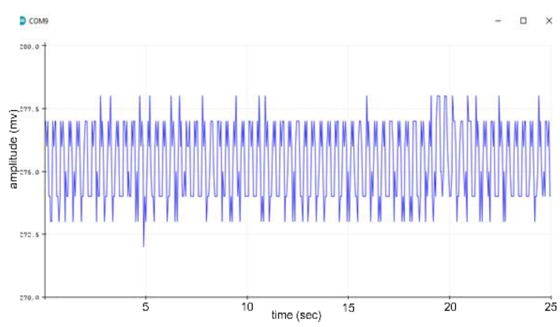

Figure 1
EMG Signal of the FCR with Muscle at Rest
Source: Own elaboration

For item c (*Control* signal), its graph is shown in Figure 2. From this, the following characteristics can be defined:

There is a *Rest* signal that shows modifications at the times marked as *t1*, *t3*, and *t5*, where a change (Δv) in its amplitude is observed. These abrupt changes occur when the fist is clenched, and the times *t2* and *t4* are the intervals when the hand is open and the muscle tension is minimal.

Box 3

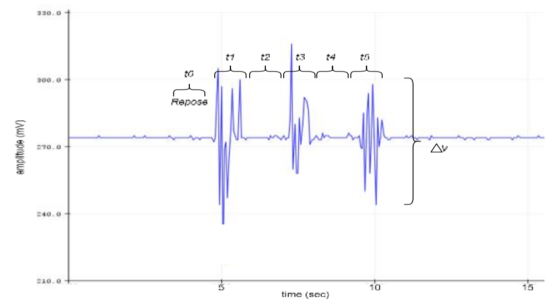

Figure 2
EMG Signal of the FCR after Clenching the Fist 3 Times with 1-Second Intervals
Source: Own elaboratio

For item b (*Normal Movements*), there are studies in the literature that investigate the kinematics and dynamics of the human arm in daily activities.

This research aims to enable the replication of a person's arm movements by a robotic arm (Rosen et al., 2005). These studies indicate that, naturally, an arm typically exhibits shoulder and elbow flexion movements, rotational movements, and object lifting. For these reasons, the experimental movements mentioned earlier were defined. Examples of these signals are shown in Figure 3, where it is not possible to determine a consistent pattern of behavior.

Box 4

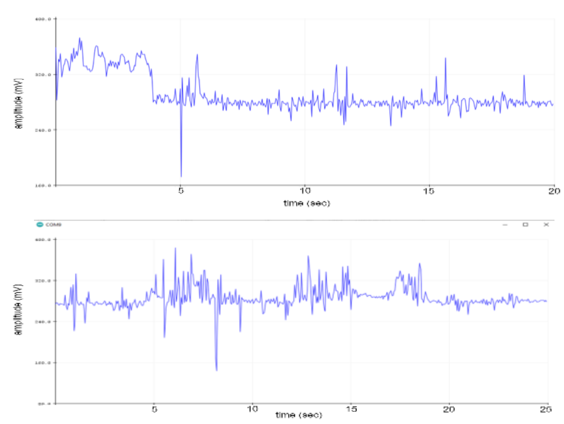

Figure 3
EMG Signals During Normal Arm Movements
Source: Own elaboration

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2.1.2 Signal Encoding

The amplitude values of each sample during the time intervals from *t1* to *t5*, shown in Figure 2, are stored in a vector ĉ, creating a discrete and finite signal. Considering that each interval contains 100 samples, the resulting vector will be segmented according to equation [2], and represents a control signal of three events, with an event being when a person clenches their first for one second.

$$ti = \hat{c}\,[n],\ \hat{c}\,[n+1], \ldots\ \hat{c}\,[n+99] \qquad [2]$$

Where:

n: is the index of the vector ĉ that identifies each position.
i: is the time interval number (1-5).

According to [2], the values of n for each interval and the amplitude values of the signal must match the data shown in Table 2.

Box 5
Table 2
Pattern of Values Defining a Control Signal

Time Interval	Value of n according to [2]	Expected Amplitude Value Δv
i=1 (t1)	0	275±30mV
i=2 (t2)	100	275± 2mV
i=3 (t3)	200	275±30mV
i=4 (t4)	300	275± 2mV
i=5 (t5)	400	275±30mV

For a *Contro*l signal to be identified, the following two conditions must be met:

i. *Synchronization Signal*. As shown in Figure 2, a *Control* signal must be preceded by an interval *t0,* which represents a *Rest* signal.

ii. *Change Patterns*. When a *Rest* signal is disrupted by sensing values different from 275 ± 2 mV, the next 500 values of the signal will be stored in a new vector ā. These values must follow the pattern defined in Table 2, which requires comparing vectors ĉ and ā.

By using the variable correlation formula, the vectors ĉ and ā are compared to determine the percentage of similarity between them, in order to ascertain whether the signal is a *Control* signal or not.

The formula adapted for this work is shown below.

$$r_{ti} = \frac{\sum_{n}^{n+99}[\hat{c}[n] - \dot{X})\ (\bar{a}[n] - \dot{Y})]}{\sqrt{\sum_{n}^{n+99}(\hat{c}[n]\ \ - \dot{X})^2 \quad \sum_{n}^{n+99}(\bar{a}[n]\ - \dot{Y})^2}} \qquad [3]$$

Where:

r_{ti} : is the correlation coefficient for the time interval *ti*.
n: is the index value of each vector according to

Table 2

Ẋ is the mean value of all the values in the vector ĉ.
Ẏ: is the mean value of all the values in the vector ā

In this way, the r_{ti} for each time interval is calculated, expecting that their average meets the condition $0.9 \leq r_{ti}$ to ensure similarity between signals.

2.2 Network Architecture

The Control signals identified in section 2.1.2 must be sent through a network system to control home automation devices. For this purpose, the following network architecture shown in Figure 4 is proposed.

Box 6

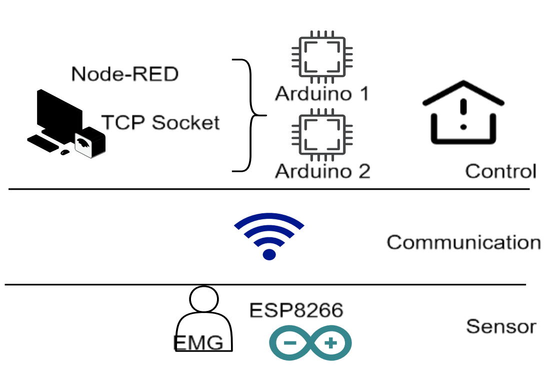

Figure 4
Network Architecture for a Home Automation System with EMG Signals and Sockets
Source: Own elaboration

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The following operation can be described from this figure:

A user employs an EMG sensor via to a wristband to generate *Control* signals. It is assumed that the sensor circuit is connected to the ESP8266 via a wired connection.

This microcontroller connects to a local computer equipped with Node-RED software through a Wi-Fi connection. The software is used to establish socket connections between the EMG user (ESP8266) and the devices to be controlled (Arduino 1 and 2).

With Node-RED, multiple simultaneous connections to various microcontrollers such as Arduino can be established. The data flow diagram and device connection through Node-RED are shown in Figure 5.

In this figure, the socket labeled as ESP8266 listens on port 8004, waiting for a connection from the microcontroller with the EMG sensor. Once communication is established, the encoded control signals are sent to a “Request” method that connects to the server named “Local Server.”

This server listens on port 8005 and forwards the control signals to a “switch” node, which acts as a selector between the two controlling devices, Arduino 1 and 2. Registered port numbers were chosen for the sockets because it is a local network, and similarly, the server address is assigned as 192.168.1.3 because it is a private device.

Box 7

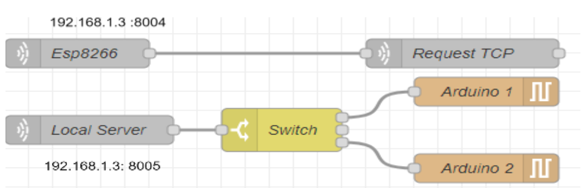

Figure 5

Node-RED Connectivity Diagram Allowing Socket Connections Between Different Nodes in a Home Automation System

Source: Own elaboration

The Arduino devices in the proposed network architecture are examples of controllers connected to home automation devices such as a light, fan, or automatic door, and they wait for a signal to operate.

3 Results

From Section 1, it can be found that electromyography has been applied to fields beyond health, such as robotics and communications.

Although there are various applications of EMG signals, no cases were found where the implementation area focuses on everyday activities like home automation and where device control is achieved without the use of a keyboard or touch panels.

In Section 2, during experimental tests with EMG signals, it was observed that different amplitude values can be obtained between individuals performing the same arm movements.

However, significant patterns can be identified that allow for the establishment of different signal types. Specifically, a *Rest* signal has minimal variation from an initial reference value, while a *Control* signal can be generally defined by its values and ranges as seen in Table 2, also starting from a reference value.

The use of formula [3] aids in the identification of Control signals. In addition, a similarity condition helps to exclude or include signals with similar patterns but different values.

The proposed logical connectivity structure, illustrated in Figures 4 and 5, allows a server socket listening on port 8004 to receive control signals, such as those coming from the ESP8266. A second server can then send these instructions to multiple home automation devices.

The idea of presenting two servers is to demonstrate that it is possible to create multiple connections within a single device and interconnect them through Node-RED.

4 Conclusions

Signals from biometric sensors often require filtering and amplification methods for better analysis. Future work will consider the use of other processing techniques and sensors to eliminate potential sources of uncertainty.

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During the use of the EMG muscle sensor, it was observed that individuals can exhibit various distinct patterns, such as the force with which they clench their fist or the speed at which they move their fingers. These behaviors are known as behavioral biometrics and could be used in future work for user recognition.

The use of client-server systems implemented with tools like Node-RED facilitates the control of flow and connectivity between devices. Unlike other systems, it is possible to integrate nodes and protocols that create solutions with various features such as storage, monitoring, and control.

Author contribution

González-Silva, Marco Antonio: Contributed to the project idea, literature review, methodology development, and article writing.

Hernández-Pérez, Faride: Contributed to defining the solution to the problem, conducting experimental tests, interpreting results, and writing the article.

Abbreviations

CFAR	Constant False Alarm Rate
EMG	Electromyography
FCR	Flexor Carpi Radialis
HAN	Home Area Network
IoT	Internet of Tings
KNN	K-Nearest Neighbor
M2M	Machine to Machine
MQTT	MQ Telemetry Transport
P2M	Person to Machine
RFID	Radio Frequency Identification

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Article

Determination of the solar fraction for optimized parabolic concentrator solar collector networks

Determinación de la fracción solar para redes termosolares optimizadas conformadas por la tecnología de colectores tipo canal parabólico

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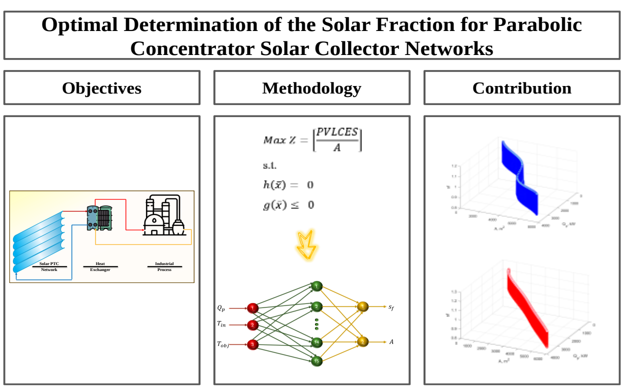
Abstract

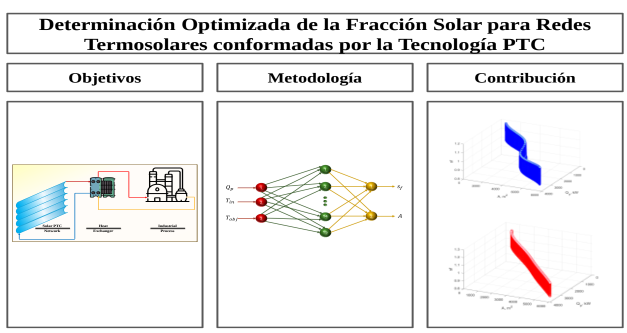
Studies show that the solar fraction of most solar thermal plants that supply heat to industrial processes ranges from 5-60%. The main limiting factor for increasing this value to 100% is the installation area. This work presents a study of the solar fraction parameter in optimized designs of systems using parabolic trough collector technology. An optimization process using Mixed-Integer Nonlinear Programming with 9 decision variables is proposed, employing the heuristic technique of Particle Swarm Optimization coupled with a transient thermohydraulic-economic model. The inlet temperature of the heat transfer fluid was varied from low to high, as well as the temperature and load required by the industrial process to obtain networks with optimized area, structure, and operating conditions. For predicting the solar fraction parameter and optimized network area, a regression using artificial neural networks was performed. It was found that it is possible to obtain flexible optimized networks capable of operating with average sf values of 1.05 throughout the year, and with a minimum area that supports changes in the operating conditions of temperature and thermal load of the process in the range of 70-400°C and 0.4-4 MW, respectively.



Solar, Fraction, Optimization, Heat, Industrial, Processes

Resumen

Estudios muestran que la fracción solar de la mayoría de las plantas termosolares que suministran calor a procesos industriales rondan en el rango de 5-60 %; siendo el principal factor limitante para incrementar este valor al 100% el área de instalación. Este trabajo presenta un estudio del parámetro de fracción solar en diseños optimizados de sistemas que emplean la tecnología de colector tipo tiro parabólico. Se propone un proceso de optimización tipo mixto entero no lineal con 9 variables de decisión, empleando la técnica heurística tipo Particle Swarm Optimization acoplada a un modelo termohidráulico–económico transiente. Se varió la temperatura de entrada del fluido de trabajo en el rango bajo a alto; al igual que la temperatura y carga requeridas por el proceso industrial para obtener redes con área, estructura y condiciones operativas optimizadas. Para la predicción del parámetro de fracción solar y área de la red optimizadas, se realizó una regresión empleando redes neuronales artificiales. Se encontró que es posible obtener redes optimizadas flexibles, capaces de operar con valores sf promedio de 1.05 a lo largo del año; y con área mínima que soporta cambios en las condiciones de operación de temperatura y carga térmica del proceso en el rango de 70-400 °C, y 0.4-4 MW, respectivamente.



Solar, Fracción, Optimización, Energía, Industriales, Procesos

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Introduction

Inevitably, economic development goes hand in hand with industrial growth. The industrial sector consumes 32-35% of the world's total energy (IRENA, 2024). Climate change has driven the creation of projects to facilitate the energy transition. The United Nations' 2030 Agenda sets goal number 7 as the use of affordable and clean energy (United Nations Sustainable Development GOALS, 2024). Recently, the UAE COP28 (United Arab Emirates - United Nations Climate Change Conference) issued an urgent call to triple renewable energy and double energy efficiency by 2030 to reduce CO_2 emissions into the atmosphere (UAE Consensus, 2024).

The economic recovery following the Covid-19 pandemic and the response to the global energy crisis have boosted investment in clean energy, reaching a record $1.7 trillion USD in the first half of 2023, compared to just $0.9 trillion USD in fossil energy investment (Birol, 2023). Solar energy is a clean and unlimited alternative that can be harnessed in various ways.

One of these is through the replacement of conventional industrial thermal processes with solar thermal networks known as Solar Heat for Industrial Processes (SHIP), (Figure 1).

In 2012, there were 25 SHIP solar thermal networks installed worldwide. By the end of 2019, this number had increased to 817, representing an increase of 187 MW. The most used technology for these systems is the Parabolic Trough Collector (PTC) (Epp & Krüger, 2017).

By 2022, 90% of SHIP networks employed PTC technology (Adib & Zervos, 2023).

As of the end of March 2023, the total installed area with PTC equipment reached 680,000 m² across 366 systems (AEE INTEC, 2024). PTC technology is characterized by its ability to achieve temperature ranges from 50°C to 400°C (Kalogirou, 2019).

Box 1

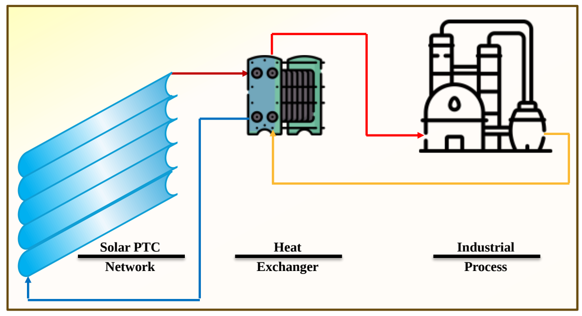

Figure 1

SHIP layout.

Source: Own elaboration

On the other hand, the solar fraction, which is the focus of this research, is an indicator used to evaluate the performance of solar thermal systems.

It compares the clean energy harvested to the energy required by the process. Despite its importance, there are few recent studies on this indicator as indicated by the following literature review.

Vanoni et al., 2006 analysed solar thermal networks in Greece, Wallonia, and Germany, focusing on industrial sectors such as chemicals, food, tobacco, textiles, and leather, among others.

They determined that a 30% solar fraction of the total energy demand of these processes is achieved. Mueller et al., 2004 conducted a technical study of solar heating plants in Austria, considering low (100°C) and medium (250°C) temperature levels, and determined an overall solar fraction of 16% of the sector's total demand.

Van de Pol & Wattimena, 2001 estimated a 30% solar fraction of the final energy demand for heating purposes in the dutch industry. They stated that the available area is the greatest limitation of solar thermal systems. Lauterbach et al., 2012 determined an overall solar fraction of 18% in the industrial sector of Germany.

The company Aiguasol analysed the Chilean industry within the APPSOL project, considering an overall solar fraction of 30% (González-García, 2018). Jia et al., 2018 found that the solar fraction in thermal industrial processes in China ranges from 5% to 10%.

In the study reported by Schweiger et al., 2000, the potential of industrial solar thermal networks in Spain and Portugal was analysed, finding a solar fraction range with minimum and maximum values of 6% to 60%.

The researchers also concluded that the available area is the limiting factor in most cases. Aste et al., 2012 determined the optimal solar fraction of hybrid collector systems (PVT - Photovoltaic-Thermal), using an economic and energy analysis with the TRNSYS platform for the cities of Rome, Palermo, and Milan (Italy

They concluded that the optimal solar fraction for these systems is 40-60%, which is lower than the recommended 70% for conventional solar thermal systems. Reiter et al., 2016 conducted a feasibility study to determine the appropriate area for the solar thermal network and thermal storage system of a district heating located in Graz, Austria, using dynamic simulation, as well as an economic and legal analysis.

They concluded that the suitable solar fraction is 9-26%, which can be achieved with an area of 150-165 thousand square meters. Pag et al., 2022 conducted a study in Germany to determine the available area using OpenStreetMap data (OSM), which is an open collaboration database project used in various educational, research, governmental, and industrial applications.

The researchers found that the available area is a limitation in 30-50% of the companies investigated. According to this study, the solar fraction in industrial SHIP systems ranges from 5-20%.

Based on the scarce information available in the open literature, the solar fraction range of installed SHIP-type solar thermal networks is between 5% and 60%, with the main limitation being the available area.

However, some questions arise: if the installation area was not a limitation, would it be preferable to aim for a solar fraction close to one in the design of a solar thermal system of these characteristics?

What is the relationship between the solar fraction and the design point at which total operating and investment costs are minimized?

This work answers these questions and presents an analysis of the behaviour of the solar fraction for different optimized design conditions for the summer and winter seasons in the city of Guanajuato, Gto., Mexico, varying the inlet temperature of the heat transfer fluid (HTF) in the low and medium ranges, as well as the temperature and thermal load required by the process in typical operating ranges.

The analysis employs a transient thermohydraulic-economic model coupled with the heuristic optimization methodology PSO (particle swarm optimization) for the design of equipment, network structure, and operating conditions that maximize thermal and economic benefits, ensuring the minimum available installed area.

Methodology

The thermohydraulic-economic model used in this research was presented and validated in the work of Lizárraga-Morazán & Picón-Núñez, 2024. The methodology includes a one-dimensional transient model for the thermohydraulic solution coupled with the economic analysis model of Present Value of Life Cycle Energy Savings (PVLCES). The methodology reported by Caballero et al., 2022 was used to determine the Life Cycle Energy Savings. The MINLP (Mixed-Integer Nonlinear Optimization) problem is presented below:

$$Max\ Z = \left[\frac{PVLCES}{A}\right]$$

$$\text{s.t.} \qquad [1]$$

$$h(\bar{x}) = 0$$

$$g(\bar{x}) \leq 0$$

Where A is the thermosolar network area. The objective function includes the two most important design parameters: the economic function that must be maximised represented by the PVLCES, and the surface area which must be minimised.

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Therefore, the ratio of these two parameters is sufficient to ensure optimal design. $h(\bar{x})$ represents the set of equations that make up the extended thermohydraulic-economic model for the solar thermal network, while $g(\bar{x})$ represents the set of constraints imposed on the system, given by the following expressions:

$$T_o^{max} \leq T_{HTF}^{lim} \quad [2]$$

$$PVLCES \geq 0$$

Where T_o^{max} is the maximum instantaneous useful outlet temperature generated by the solar thermal network during daily operation (9 AM – 6 PM); T_{HTF}^{lim} is the operating limit temperature of the heat transfer fluid (HTF), and sf is the solar fraction defined by the following expression:

$$sf = \frac{Q}{Q_p} \quad [3]$$

Where Q_p is the thermal load required by the process. Q is the total useful integrated heat, representing the total energy harvested by the network at the outlet temperature level required by the industrial process (T_{obj}).

This value results from the integration of the instantaneous useful energy gained by the heat transfer fluid (HTF) during the operation time.

$$Q = \int_{t=9\,h}^{t=18\,h} q_t dt \quad [4]$$

In the optimization problem, nine decision variables were considered, including the dimensions that define the geometry of the PTC: lengthL_c, aperture width W_{aper}, receiver diameter D_i, glass envelope diameter D_{gi}, and PTC focal length f.

Additionally, it includes variables that define the size and structure of the network: number of collectors per line N_{cl} and total number of network lines N_L.

Finally, the model also optimizes the mass flow rate of the HTF to the network $\dot{m}_f$ and the type of HTF. Four widely used commercial fluids were considered in the analysis: pressurized water, Syltherm-800, Therminol VP-1, and Dowtherm-A.

To solve the optimization problem, the stochastic Particle Swarm Optimization (PSO) methodology was employed.

In this technique, potential solutions are identified as particles with memory, allowing them to recognize the best solution within the feasible search space (Sharma et al., 2012), (Afzal et al., 2023).

The optimization problem was solved by varying the thermal load required by the process Q_p, the inlet temperature of the heat transfer fluid T_{in}, and the temperature required by the process (T_{obj}) over wide intervals for typical winter and summer days. These ranges are presented in Table 1.

Box 2

Table 1

Independent Variable Range

Q_p (kW)	400 - 4,000
T_{obj}(°C)	70 - 400
T_{in} (°C)	$(0.7 - 0.9) \cdot T_{obj}$

Source: Own elaboration.

Table 2 presents the parameter search space. The limits of the selected decision variables are taken from commercial equipment reported in open literature *(*Afzal et al., 2023*)*.

Box 3

Table 2

Parameter search space

L_c (m)	2-15
W_{aper} (m)	0.5-9.3
D_i (m)	0.01-0.08
D_{gi} (m)	0.1-0.2
f (m)	0.2-3
N_{cl}	1-40
N_L	1-200
$\dot{m}_f$ (kg·s^{-1})	0.1-10
HTF	Syltherm-800, Dowtherm-A, Therminol, VP-1, Pressurized water

Source: Own elaboration.

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To have a representative sample of the ranges of the independent variables, specific values for Q_p, T_{in} and T_{obj} were selected to cover the defined intervals. The process thermal load was divided into four levels: 400, 1,600, 2,800, and 4,000 kW.

The target temperature was divided into seven levels: 70, 125, 180, 235, 290, 345, and 400 °C; and the inlet temperature was divided into three levels: 0.7, 0.8, and 0.9·T_{obj}.

The optimization problem was solved for each of the 84 combinations of Q_p, T_{in} and T_{obj}; and for each season. Instantaneous daily environmental data on irradiance, ambient temperature, and wind speed collected in the city of Guanajuato (21.0190° N, 101.2574° W) at the facilities of the University of Guanajuato, Mexico, were used.

The results obtained regarding the geometry of the PTC equipment that makes up the network, the size and structure of the network, and the optimized operating conditions are reported in the work of [XIX].

Finally, the solar fraction performance parameter was determined for each combination of winter and summer samples, and the regression process was carried out using classical multivariable polynomial regression techniques and neural networks.

In this work, neural network regression was successfully used to predict the solar factor and network area, as conventional regression did not yield reliable statistical results.

The multilayer perceptron (MLP), also known as a feed-forward neural network (FFNN), was the model selected for this work.

Typically, the use of MLP in regression problems requires only one hidden layer, in addition to the input and output layers.

The Levenberg-Marquardt (LM) algorithm was used in the optimization, and the sigmoid transfer function was employed in the hidden layer for signal translation between the layers of the MLP network.

Figure 2 illustrates the structure of the MLP model used in the regression for predicting the solar fraction and the area of the solar thermal network.

Box 4

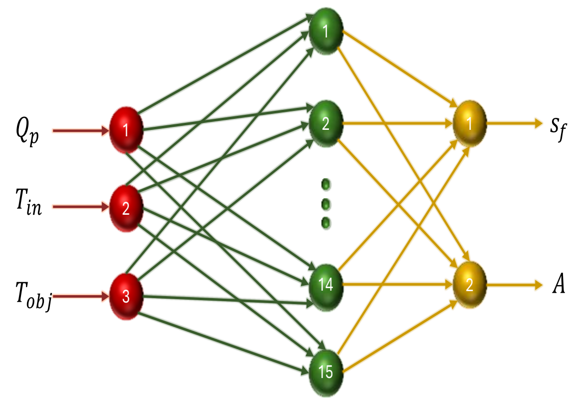

Figure 2

Structure of the MLP used on A - sf regression

Source: Own elaboration

Results

Figure 3 presents the profile of the solar fraction concerning the solar thermal area and the thermal load required by the process.

The set of points in a single colour represent the different combinations of inlet temperature and the temperature required by the process for the same heat load.

It is interesting to note that the proposed optimization process can generate flexible solar thermal networks, where the installed area allows operation over a wide range of operating conditions forQ_p, T_{in} and T_{obj}; while maintaining high solar fraction values.

Table 3 summarizes the most relevant statistical data of the optimized solar fraction for the winter and summer samples.

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Box 5

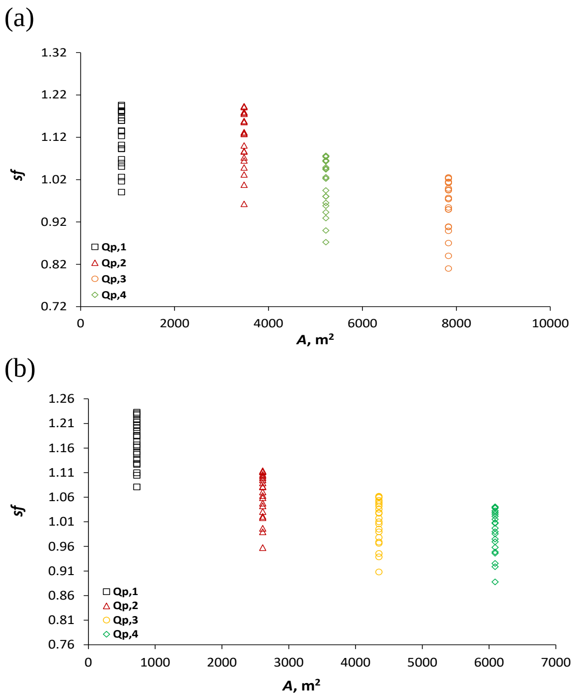

Figure 3

sf – A profile: (a) winter and (b) summer

Source: Own elaboration

Box 6

Table 3

sf statistics

	Winter	Summer
Mean	1.050	1.057
Std Dev	0.0938	0.0837
Min	0.8100	0.8993
Max	1.1962	1.2296

Source: Own elaboration

The previous statistical results show that the average solar fraction obtained for the winter and summer samples meets the thermal requirements of the industrial process within the range of the independent operating variables.

To carry out the regression with an ANN (artificial neural network), 70% of each sample was used for training, and the remaining 30% was equally divided for validation and testing.

The ANNs constructed for the regression required 15 perceptrons in the hidden layer.

Table 4 presents the most important statistics of the ANN regression.

Box 7

Table 4

ANN regression statistics

	Winter		Summer	
	sf	***A***	***sf***	***A***
MSE	$2.7e^{-4}$	$3.5e^{-3}$	$2.7e^{-5}$	$4.7e^{-4}$
RMSE	$1.7e^{-2}$	$5.9e^{-2}$	$5.2e^{-3}$	$2.2e^{-2}$
R^2	1.00	0.99	1.00	0.99

Source: Own elaboration

Figure 4 graphically shows the fit of the ANN regression for the solar fraction for the winter and summer seasons concerning the area and the thermal load required by the process.

Box 8

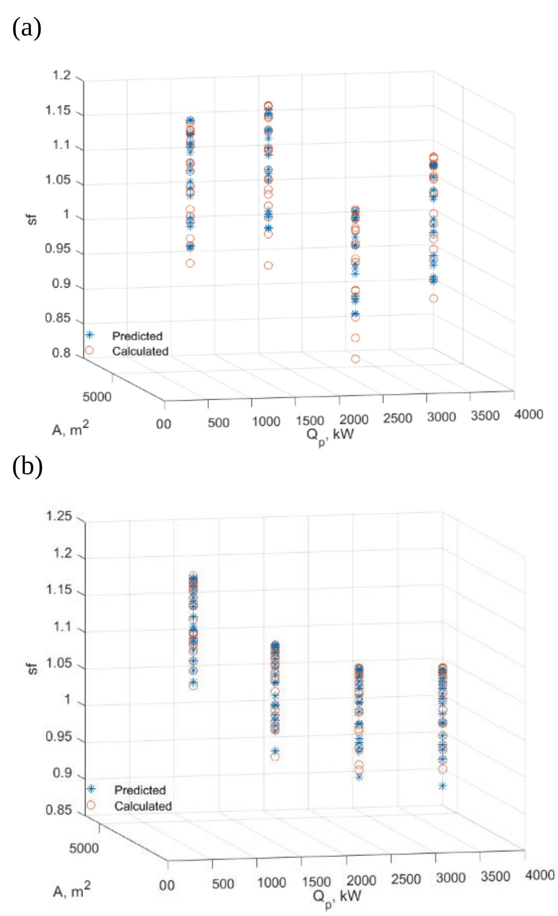

Figure 4

Fitness of the sf-A regression model: (a) winter and (b) summer

Source: Own elaboration

Figure 5 presents the profile of the solar fraction estimated through the ANN regression.

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Box 9

(a)

(b)

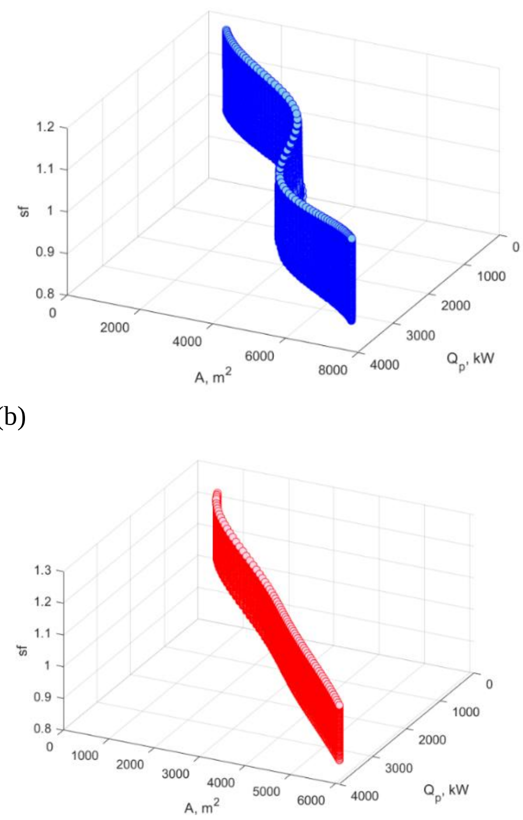

Figure 5
sf - A performance profile: (a) winter, and (b) summer
Source: Own elaboration

Conclusions

From the previous research, the following conclusions can be drawn:

The proposed optimization process ensures flexible solar thermal networks capable of operating over wide ranges of inlet temperature, process load, and process temperature, generating average solar fractions of 1 for the extreme winter and summer seasons. This allows the thermal requirements of the industrial process to be met throughout the year.

The ANN regression model successfully predicts the behaviour of the variables (sf) and (A) of the solar thermal network for both seasons.

The solar fraction decreases with respect to the required thermal load and the area of the solar thermal network. This effect is more pronounced in the winter season.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Authors' Contribution

Lizárrga-Morazán, Juan-Ramón: Contributed to the research methodology and generation of results and writing of the manuscript.

Picón-Núñez, Martín: Contributed to the project idea, research method, editing and revising of the manuscript.

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Abbreviations

ANN	Artificial neural network
FFNN	Feed forward neural network
HTF	Heat transfer fluid
MLP	Multilayer perceptron
PVLCES	Present value of life cycla analysis
SHIP	Solar heat for industrial processess

Nomenclature

A	Network area, [m^2]
D_i	Receiver inner diameter, [m]
Dg_i	Glass envelope inner diameter, [m]
f	Focal distance, [m]
L	Row length, [m]
L_c	PTC length, [m]
$\dot{m}_f$	Mass flow rate, [kg/s]
sf	Solar fraction
N_{cl}	Number of collectors per row, [coll/row]
N_L	Number of network rows
Q_p	Process heat, [kW]
Q	Useful heat, [kW]

q_t Instantaneous heat, [kW]
T_{in} HTF Inlet temperature, [°C]
T_{obj} HTF target temperature, [°C]
T_{HTF}^{limit} HTF limit outlet temperature, [°C]
T_o^{max} Maximum outlet temperature, [°C]
t Time, [h]
W_{aper} Width aperture of the PTC, [m].

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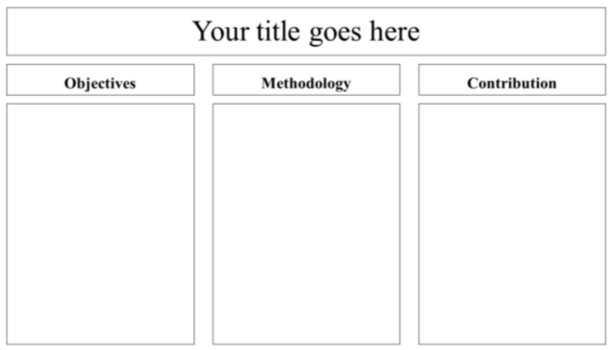

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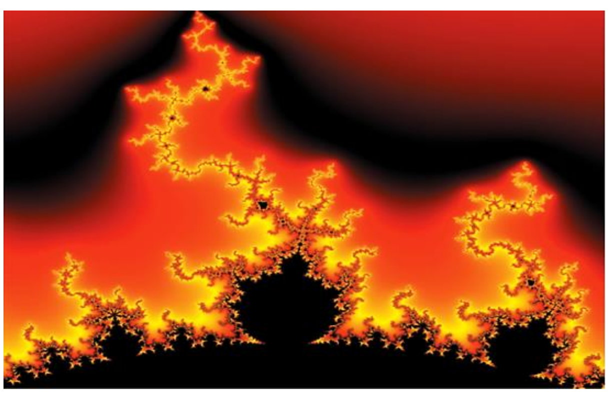

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