Technical and market evaluation of thermal generation power plants in the Colombia power system

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ABSTRACT

Thermal power plants are the widely conventional generation unit technology used to produce electricity being controllable and dispatchable. The location of thermal power plants depends on the energy availability conditions of the areas and the capacity to fuels access. Their location and geographical distribution define a high level of concentration in areas defined as thermal districts and its location define reliability, security, availability, and flexibility indices to avoid critical scenario or support system from contingencies. However, in many cases the electrical configuration does not correspond to requirements. This paper links the concentration by political distribution in Colombia and the configuration used in the generating substations to guarantee requirements. The Hirschman-Herfindahl index as a market tool is used to evaluate energy concentration facing representative participation in certain departments of Colombia. Results evidenced configurations and concentration in a study case, results and analysis could be used for planner to promote participation, reliability and promote. The paper's contribution and conclusions are linked to guide planners towards market and technical tool to evaluate installed capacities, avoid market concentration, and reduce risky scenarios.

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1. INTRODUCTION

A thermal power plant converts of a steam boiler fueled by coal, natural gas, heating oil, or biomass, burning some sort of fuel, to produce electricity [1]. These conventional generation units produce electricity in a dispatch scenario or unit commitment in large quantities for energy use in cities and communities [2]. Global trends towards sustainable development such as affordable and clean energy (goal 07), sustainable cities and communities (goal 11), climate actions (goal 13), as well as the Kyoto protocol focused on control of greenhouse gas emissions to stop global warming has motivated nations and regions toward the reduction of thermal units around the world and has guided to renewable energy with zero contribution of gases to the environment. In addition, the high dependence on fossil resources, which are expensive in some region to acquire and increase the final cost of electricity.

In Colombia, there are different thermal power plants interconnected in the Colombian power system, which must comply with a series of conditions to be connected. A thermal power plant can be designed and sized to handle different thermal generation sources, among which biomass and fossil fuels stand out [3]. The location of thermal power plants depends on the energy availability conditions of the areas and the availability of fuels. In areas where the development of hydroelectric generation sources is not feasible, it is considered the promotion and development of thermal power plants, which have an intermediate investment cost, with an occupation area (m^2) smaller than hydro [4].

The thermal power plants in Colombia allow, under a hydrothermal scenario, a backup in the energy mix that is required to guarantee an adequate substitute for contingencies and rationing. However, the implications are based on the requirements of power systems, which involve guaranteeing the supply of energy to cities and communities requiring security, reliability and flexibility in transformation and distribution centers [5]. In a centrally dispatched generation power plant, the fundamental requirement is reliability, being then the availability of modular generation elements, stages and substation configuration designed to respond to these indicators. Additional responsibilities may require that power configuration must guarantee security and flexibility if the requirements are distribution or transmissions activities respectively [6]. In future plants, the country should forecast new thermal units due to the demand growth, as shown in [7].

This research establishes a review of the state-of-the art and the conceptual foundations that relate the elements and systems that make up a generation plant to the substation configurations that allow connection to the power systems in section 2. Section 3 presents how the analysis that allows to evaluate the reliability of the substation configuration schemes that accompany the generation plants is approached, taking as a reference case the generation plants in Colombia that take part in the centralized dispatch, which is also categorized by the political distribution within the country. Section 4 reviews the generation plant technologies present in Colombia-based on the substation configurations to evaluate reliability that these represent in the system in order to point out those arrangements that, because of technical conditions of the system, must be improved, which may cause failures and contingencies that lead to the exit of the configuration and the total or partial loss of the required generation. Finally, section 5 presents conclusion to be considered.

2. STATE OF ART

Thermal power plants are also known as conventional power plants. They develop a centralized dispatch using different hydrocarbons derived from fossil resources gas, coal, oil derivatives, and biomass. They can produce electricity in large quantities, guaranteeing the energy supply to loads [2]. This section describes the thermodynamic cycles presented in a thermal power plant, the generation substation requirements and the substation configurations used.

2.1. Thermodynamic cycles present in a conventional thermal power plant

Thermal power plants use a combined cycle (Rankine and Brayton). Gas turbines work with a cycle called the Brayton cycle and steam turbines work with a cycle called Rankine cycle, which in the Brayton cycle heat is rejected and in an isobaric process is the energy that is used in a Rankine cycle to perform the production of steam, in both cycles work is done where heat is rejected in an isentropic process [8], [9]. The isobaric processes manage the combustion system of gas and steam turbines uses, in the isentropic processes is where the processes of compression (compressor) and expansion (turbine expander) occur in gas turbines. As the pressure and temperature rise, the efficiency of the Brayton cycle increases [8], [9]. The overall efficiency of the cycles because the fact that the gas is caloric and thermally perfect, so the specific heat at constant pressure and specific heat at constant volume are constant processes so that the specific heat ratios remain constant over a long cycle, if the specifications of the compressor and the turbine are the same, the equipment operates at 100% efficiency [10]. One cycle to consider is the Kalina cycle, which had been widely used in the 1980s, whose main characteristic is the working fluid used considering binary mixtures such as ammonia (NH3) and water (H2O) as the typical compounds [11]–[14]. Table 1 describes the most common cycles used in thermal units such as Rankine, Brayton and Kalina, among others.

2.2. Thermal power plant

A thermal power plant (plants that operate with carbon-based fuels, such as coal, natural gas, and oil derivatives). Table 2 describes each power plant with their respective cycles and types of thermal power plants currently in use [10]. While the steam turbine uses a Rankine cycle, a single-cycle gas turbine considers a Brayton cycle typically. The cogeneration process uses both cycles (Rankine and Brayton).

Table 1. Rankine, Brayton and Kalina cycles literature review

No.	Year	Name of document	Cycle	Contribution	Ref.
1	2022	Solar energy materials and solar cells critical components in supercritical CO2 Brayton cycle power blocks for solar power systems: degradation mechanisms and failure consequences.	Brayton	Operating at temperatures above 700 °C has been shown to increase system efficiency by over 50%. Using a Brayton cycle power block, the next generation of the concentrating solar power (CSP) operates at temperatures above 700 °C. It is concluded that Brayton cycles provide the highest possible efficiency to a power generation system.	[9]
2	2022	Design and modeling of a honeycomb ceramic thermal energy storage for a solar thermal air-Brayton cycle system.	Brayton	This document studies the components of a gas microturbine, a recuperator, an air receiver, and a thermal storage tank.	[15]
3	2022	Combinations of Rankine with ejector refrigeration cycles: recent progresses and outlook.	Rankine	It focuses on the combination of the refrigerant injection and Rankine cycles. As the combination of cycles, to improve the overall efficiency of the Rankine cycle and decrease waste heat.	[13]
4	2022	Is Kalina cycle or organic Rankine cycle for industrial waste heat recovery applications? a detailed performance, economic and environment based comprehensive.	Kalina Rankine	The Kalina cycle is compared as the best waste heat recovery system with the Rankine cycle in terms of investment costs, environmental impact, and thermodynamic performance.	[11]
5	2022	Solar organic Rankine cycle and its poly-generation applications - a review.	Rankine	The solar Rankine cycle is one of the most reliable renewable energy-based technologies for meeting major energy demands. The study focuses on cogeneration, regeneration and poly generation applications of the organic solar Rankine cycle, the organic Rankine cycle. Future work focuses on the need for studies based on poly generation and to consider the review of hybrid systems that allow working with solar technologies, among which solar collectors stand out.	[14]
6	2021	Thermodynamic design space data-mining and multi-objective optimization of SCO2 Brayton cycles.	Brayton	The addition of a low temperature recuperator and a recompression unit are added to the simple Brayton cycle, forming an SCO2 recompression Brayton cycle (SCO2RBC). This cycle avoids the pinch problem of simple cycles and improves the efficiency of the Brayton cycle.	[8]
7	2021	Power generation in white cement plants from waste heat recovery using steam-organic combined Rankine cycle.	Rankine Kalina	There are three cycles for the generation of electrical energy from waste heat, these cycles are: Rankine cycle, the organic Rankine cycle and the Kalina cycle. A combined cycle is the combined organic steam Rankine cycle or cascade organic Rankine cycle.	[16]
8	2020	Gas turbine combined cycle power plants.	Rankine Brayton	An updated definition of Rankine and Brayton cycles is presented. The Rankine is a closed cycle in which the mass flow rate of the working fluid and its composition do not change. The Brayton is an open cycle. The mass flow of the working fluid and its composition change from the compressor inlet to the turbine exhaust, while its phase does not change.	[12]

2.3. Generation substations

An electrical substation is an electrical node of a power system in which energy is transformed to suitable voltage levels for transport, distribution, or consumption, with certain quality requirements. It comprises a set of equipment used to control the flow of energy and ensure the security of the system by automatic protection devices. Electrical substations are fundamental elements to generate, transport and distribute energy to its ultimate use and protection schemes [17]. The generation electrical substations are in charge of directly controlling the power flow of the system because the production generated by them is directly injected to a transmission network associated to this substation, as well as the maneuvering and distribution substations that belong to its associated network [6]. There are four main types of electrical substations worldwide [18]:

- Switchyard at a generating station: These facilities connect generators to the power grid and provide off-site power to the plant. Typically, is considered as a step-up substation and is near power plant facilities. The switchyard in a power plant are large facilities typically designed and constructed by the power plant designers and are subject to different planning, financing, and construction efforts than routine substation projects. The requirement at this substation is the reliability [18].

- Customer substations: It refers to a final user substation, functions as the primary source of electrical power supply for a particular commercial, industrial or residential. Users operates and handle its operation and the requirement to be supported is focused on security [18].
- Interconnection or transfer substations: This substation operate based on switching elements, manoeuvres and control between area are the main activities transporting large block of electricity, for that reason they must be flexible to support operation between different agents [18].
- Distribution substations: These are the facilities controlled by utilities, as they are usually near load centres. This type of distribution substations include switchyards at secondary distribution level as customers substation and the main requirement is the security [18].

Table 2. The most commonly cycles used in thermal power plants

Type	Description	Cycle
Steam turbine power plants	Electricity is produced by a turbine, comprising a boiler containing steam at high pressure and high temperature. This causes that the turbine rotates at high speed and this turbine drives a generator to produce electricity.	The steam turbine follows the Rankine cycle.
Single-cycle gas turbine plants	Gas turbines compress the air in the compressor, the air is heated to a high temperature at constant pressure. The air coming out of the combustion chamber at constant pressure, and this performs the expansion to perform the movement of the generator and thus produce electrical energy.	Gas turbines use the Brayton Cycle.
Combined cycle power plants	The steam is used in a steam turbine to produce additional electrical energy. Technically, however, the term can be used for any combination of cycles. Combined cycle power plants have been in use since the mid 50's, these plants are improving, and the turbines are coming with better capacities and efficiency.	It is usually a combination of the Brayton cycle (gas turbine) as the upper cycle and the Rankine cycle (steam turbine) as the lower cycle. Many small plants use the diesel cycle as the upper cycle, with the Rankine cycle as the lower cycle; plants also use the Brayton cycle as the upper and lower cycles.
Cogeneration power plants	This generation produces energy in one or more forms from a single power plant. These plants are most used in terms of electrical generation and steam processes.	It must use the two cycles: the Brayton cycle (gas turbine) as the upper cycle and the Rankine cycle (steam turbine) as the lower cycle.

Source: adapted from [10]

2.4. Configuration diagrams

To select a configuration for a substation, its application defines its requirements and properties. Then, the reliability, security, modularity, flexibility, and availability during maintenance, contingencies, operation, maneuvers establish parameters and elements distribution in a switchyard, as is shown in Table 3 [6]. These requirements must accomplish the following trends and requirements.

- Reliability: This requirement promotes operation during contingencies such as an n-1, caused by a sudden output of an element [19]. The most robust the system and redundant the most dependable during a scenario and focused on post-contingency operation. Utilities and operators focus efforts on redundance, duplicity to make a robust and reliable power system.
- Security: It means to guarantee electricity support all the time of final users, including contingencies scenarios. A secure system must support several problems in a power system. A power system must be able to support load considering a wide variety of circumstances, which must guarantee that the system or other part of the system do not lose the remaining loads. Also, the control strategies on the power system must wide to a post-contingency scenario toward a controllable situation, avoiding blackouts or outages [20].
- Flexibility: The requirement related to support the configuration. In a power system, to lose a configuration implicates to do not have flexibility. The configurations in substations must limit short-circuit current, prevent load currents exceeding the current ratings assigned to the busbars, and arrange incoming and outgoing circuits to accommodate system setting conditions, without losing the configuration [6].
- Availability: Each element that is unavailable caused by maintenance must be reported and measured using an index, these indicators are guided to control the operation. The availability as requirements guarantees coordinated activities to support elements [6].
- Modularity: the ability of a configuration to adapt to future changes in technology by adding modules, sections, or components [6].

Table 3. Typical electrical configurations and their typical constraints and problems

Configuration	Type	Associated problems
Single bar	Bars	Reliability: There is only one element to support the operation. Security: The probability of array failure compromises the continuity of supply. Flexibility: There is a possibility of loss of the configuration in the event of bar failure and/or unsupported contingencies in the connected circuits. Availability: There are no backup elements to guarantee the operation.
Double bar	Bars	Reliability: They improve the reliability by adding a busbar that supports 100% of the operation. However, there are restrictions in the connection to each of the circuits. Security: There are supply continuity problems in the event of contingencies and maintenance of the circuit breaker and dis connectors. Flexibility: There is a probability of loss of the configuration due to bar fault. An alternative for the operators is to work with an open disconnector to reduce the risk of loss of the configuration in the event of a fault. Availability: There is no back-up for maintenance of disconnectors and circuit breakers.
Double bar with by-pass	Bars	Reliability: There are additional elements to guarantee operation under scenario n-1. Security: The continuity of supply is guaranteed even in maintenance and contingency scenarios in the circuit breaker, which is replaced by the by-pass disconnected. Flexibility: There is a risk of no power being supplied in the event of a bar failure. A circuit operated with the by-pass disconnect can generate a transfer or remote trip that compromises operation and loss of configuration. Availability: There are alternative elements to guarantee operation in the event of maintenance. Two energized busbars with capacity to support 100% of the operation.
Double busbar with transfer switch	Bars	Reliability: There are additional elements to guarantee operation under scenario n-1. Security: The continuity of supply is guaranteed even in maintenance and contingency scenarios in the circuit breaker, which is replaced by the transfer switch. Flexibility: There is a risk of unattended operation in the event of a bar failure. A circuit operated with the transfer switch can generate a transfer trip or remote trip that compromises the operation and loss of the configuration. Availability: There are alternative elements to guarantee operation in the event of maintenance. Two energized busbars with the capacity to support the operation of 100% of the capacity.
Ring	Switches	Reliability: I used it the ring concept to supplying electricity to circuits. Security: The maintenance of a circuit breaker does not compromise the supply of the connected circuits, but the safety of the operation is affected. Flexibility: The opening of the array caused by the operation of the switch affects the configuration. It is recommended to limit the operation to a maximum of six circuits. The dangerous operation of one circuit can compromise the operation of the adjacent circuit, so it is not recommended to connect power supplies in a row. Availability: In the event of maintenance or failure, there are alternative elements around the ring. There are risks of inattention in case of the failure of the disconnector that connects the load to the ring.
One-and-a-half	Switches	Reliability: There are additional elements based on a switching scheme to power the circuits in two different modes. Security: The incorrect operation of one circuit may compromise the operation of the adjacent circuit. It is not recommended to connect adjacent power supplies so as not to affect the supply. Flexibility: The risk of short-circuit bar failure is eliminated. An unplanned contingency or scenario can affect the operation of the adjacent circuit. Availability: There is a redundancy of elements. There are risks of inattention in case of failure of the disconnector that connects the configuration to the load.

3. METHOD

The development of the research is considered in four phases or stages, starting with the identification and location of the generation plants in Colombia, identifying generation capacities and configurations. Then, the electrical power system is evaluated in a single-line diagram focused on reliability, security, and flexibility requirements. The entire power system scheme is evaluated based on the economic index to evaluate market competition to finally evaluate the configuration behavior. Figure 1 describes the procedure used to evaluate thermal scenario and market concentration.

3.1. Description of the context of thermal power plants

The thermal power plants in Colombia represent 33% of the country’s energy matrix. In the hydrothermal dispatch model used, they operate as the backup of hydro-electrical power plants. However, they contributes with ancillary service such as security generation and constraints in power system areas [18]. The electric power generation capacity in Colombia through the process of thermal power plants is part of a group of 18 plants, which works in 12 departments of Colombia and handle different fuels, technologies and configurations for the generation of electric power and its connection to the grid [21].

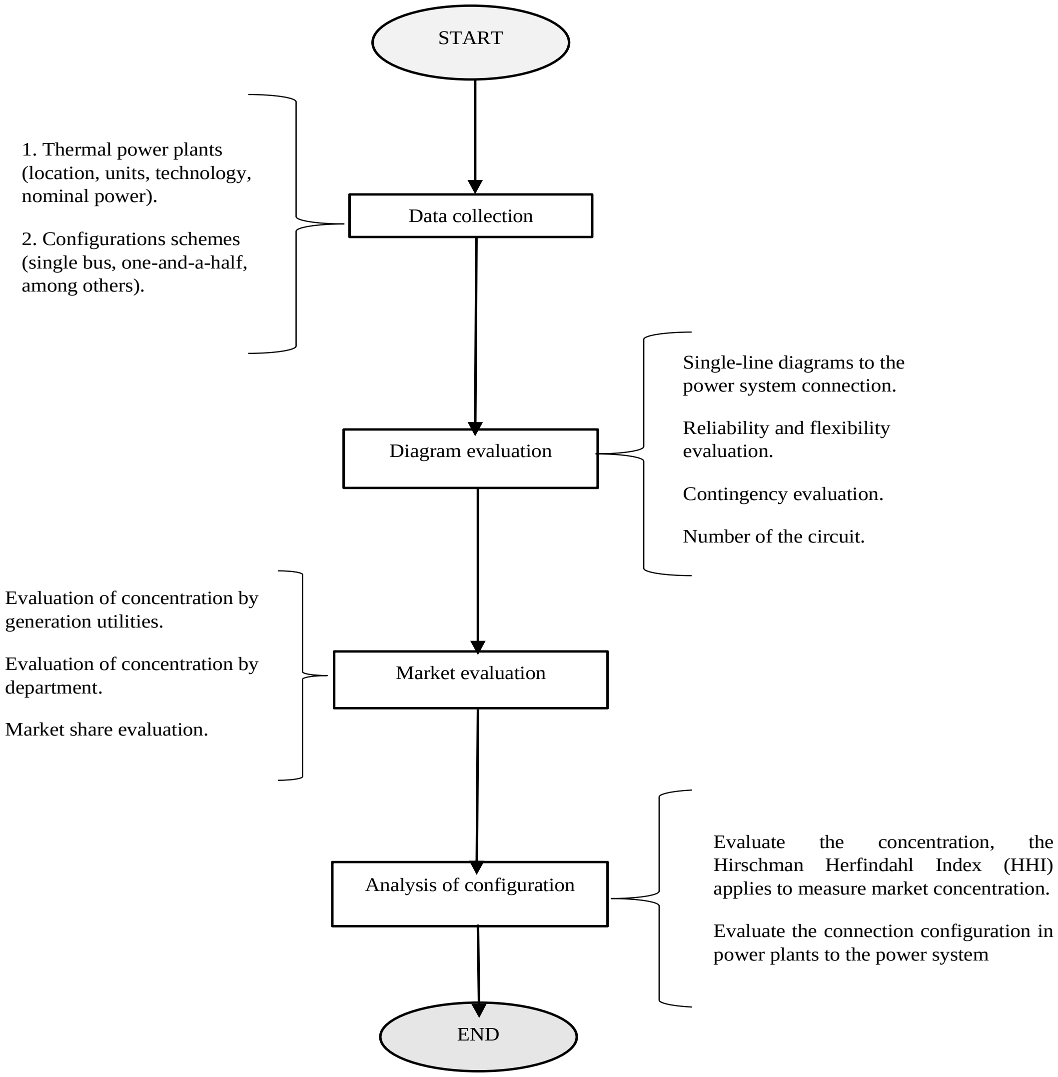

Figure 1. Method of analysis

3.2. Information gathering and analysis

The following steps were taken to search for data on thermal generation plants in Colombia:

Step 1: The information related to technologies, capacities associated with firm energy obligation (OEF) available and declared by each of the thermal generation plants were got from the Colombian electricity information system (sistema de información eléctrico Colombiano) [19]. Focusing the research on thermal generation plants that can take part in the dispatch (units with capacity over 20 MVA) [22]. Focusing the research on thermal generation plants that can participate in the dispatch (units with capacity over 20 MVA).

Step 2: The information related to technical specifications and review of single-line diagrams of the generation plants was merged with the information provided by the planner [23], [24].

Step 3: An identification of the thermal districts is made presenting the representation of the participation by political division (departments) showing the concentration and representation of the thermal power plants. To evaluate the concentration analysis, the Hirschman Herfindahl index (HHI) applies to measure market concentration.

$$IHH = \sum_{i=1}^{n} S_i^2 \quad (1)$$

The market participation is expressed in percentages S_i, and i is the number of power plant units considering political distribution. Within the ranges contemplated for evaluating the index, the concentration ratio for the scenario will be taken as a reference. Table 4 describes the market concentration level.

Table 4. Market concentration level

HHI result	Concentration	Market trend
Less than 1,000	Poorly concentrated	Perfect competition
between 1,000 and 1,800	Moderate concentration.	Oligopolist
More than 1,800	High concentration.	Monopolist

Source: adapted from [25], [26]

Step 4: For the technical analysis, the configuration used for power plant units is evaluated regarding the declared capacity of each taking part generation unit. The evaluation is oriented to describe the problems that may occur when connecting a generation unit. Highlighting the arrangements and the risk of demand dissatisfaction that may occur in configurations that support the operation according to its relevance on the electrical power system.

4. RESULTS AND DISCUSSION

4.1. Generation capacity by political distribution

Table 5 shows a statistical analysis of the data according to the amount of generation capacity declared by departments. This allows to identify thermal districts into the political distribution by department focusing on those that support power system with thermal power plants units. The Department of Atlántico has the maximum generating capacity percentages of thermal generation in Colombia, gathering the 28.54% of the total electricity generated with thermal power plants, which are formed by two companies that provide an energy obligation equal to 1,521 MVA. These capacity of power to the interconnected system and if in some of the cases these two thermal power plants fail, almost 30% of the total generation by thermal power plants would decay. Should these two thermal power plants fail, almost 30% of all thermal power plant generation would be lost.

In the Bolivar region there are three thermal generators that together contribute 10.96% of the thermal generation in Colombia, occupying the second place with the highest generation with a capacity of 584 MVA of power to the interconnected system. The Valle del Cauca in the thermal generation process contributes 10.23% of the capacity to the interconnected system, with a power of 545.1 MVA produced by it is 2 generators. The Casanare, the 2 thermal generators together generate a capacity of 466 MVA, which represents 8.64% of the interconnected system's capacity by thermal generators.

The thermal generators located in Santander have the capacity to produce a total power of 429 MVA, which has 2 large generators which would contribute 8.24% of the total capacity generated by thermal power plants. In Cordoba there are 2 thermal power plants capable of generating 437 MVA, this generation has 8.20% of the total capacity generated by thermal power plants. In Antioquia there is total thermal power plant contribution equal to 353 MVA (6.62%) and Norte de Santander supports with the 6.29% which is equal to 335 MVA.

A thermal power plant in the Guajira has a generation capacity of 290 MVA, which is equivalent to 5.44% of the national percentage of thermal power plant generation. Cundinamarca, located in southern Colombia, has a generating capacity of 226 MVA (4.24% of thermal power plant generation). In Magdalena is located one of the smallest generation plants at national level with the capacity to generate 88 MVA which covers 1.75% of the national generation and the plant located in Caldas which has a generation capacity of 45 MVA is the one with the lowest declared generation capacity in the interconnected system of Colombia, occupying 0.84% of the total generation of thermal power plants in Colombia.

Table 5. Generation capacity and concentration by political distribution in Colombia

Department	Nominal power (MVA)	Percentage (%)	HHI
Atlántico	1,521	28.54	814.53
Bolívar	584	10.96	120.12
Valle del Cauca	545.1	10.23	104.65
Casanare	466	8.74	76.38
Santander	439	8.24	67.89
Córdoba	437	8.20	67.24
Antioquia	353	6.62	43.82
Norte de Santander	335	6.29	39.56
Guajira	290	5.44	29.59
Cundinamarca	226	4.24	17.97
Magdalena	88	1.65	2.72
Caldas	45	0.84	0.70
Grand total	5329.1	100.00	1385

4.2. Generation capacity per configuration

Table 6 shows the total generation by thermal power plant according to their connection configuration. Highlighting that thermal power plant with high responsibility with power system must support contingencies, operational changes, and maintenance, being the one-and-a-half configuration and the double bar with by-pass to guarantee these requirements, however, the single bus bar, ring and double bus bar configuration could be restricted in reliability and security. It can be evidenced that in the department with high concentration of thermal units (thermal district) there are units connected to that meet reliability and security requirements, but there are restrictions in some parts of the system where it is not possible to guarantee contingencies scenarios, being a 38.49% of the total power supported restricted.

Table 6. Generation capacity in Colombia according to its configuration

Department	Configuration	Number of units	Energy obligation (MVA)	Participation
Atlántico	Double bar with by-pass	5	610	11.45%
	One-and-a-half	7	911	17.09%
Bolivar	Single bar	2	90	1.69%
	One-and-a-half	5	494	9.27%
Valle del Cauca	Single bar	2	241	4.52%
	Double bar	2	304.1	5.71%
Casanare	Single bar	3	128	2.40%
	Double busbar with transfer switch	4	338	6.34%
Santander	Single bar	3	439	8.24%
Cordoba	Ring	2	437	8.20%
Antioquia	Double bar	3	353	6.62%
Norte de Santander	One-and-a-half	2	335	6.29%
La Guajira	One-and-a-half	2	290	5.44%
Cundinamarca	Single bar	4	226	4.24%
Magdalena	One-and-a-half	1	88	1.65%
Caldas	Single bar	1	45	0.84%

In Figure 2 the information shown in Table 6 is analyzed using a pie chart to demonstrate the power declared by thermal power plants according with the configuration. Considering the above graph, it is observed the declared generation capacity by type of configuration used in thermal power plants, with 39.74%, it is considered that the thermal power plants in Colombia use the configuration of one-and-a-half with a generation capacity of 2,118 MVA, since this type of configuration indicates a reliability and security index in case of failures in any of the circuits. A thermal power plants that use single busbar configuration occupy 21.94% of the generating capacity of thermal power plants in Colombia, however, this type of configuration does not meet the optimum levels of reliability, security, or flexibility.

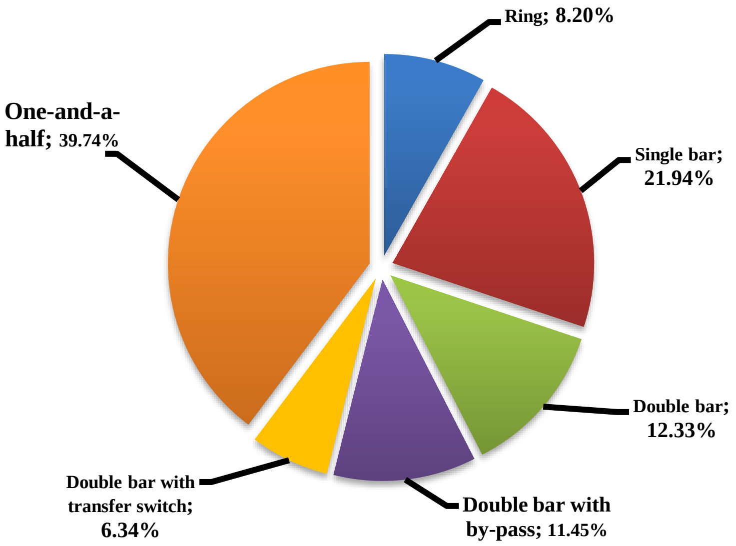

Figure 2. Generation capacity according to its configuration in MVA and percentage

A thermal power plants that use the double busbar configuration occupy 12.33% of the thermal generation capacity in Colombia, consisting of double busbars that allow us to have a high reliability and flexibility index, for the system and its operation in terms of failures or scheduled processes, also the thermal power plants with double busbar configuration and bypass occupy 11.45% of the capacity generated in Colombia increasing the indexes in terms of flexibility for the system. A ring configuration in their generation system contribute 8.20% of the generating capacity; this configuration has a high secure and reliability index. It is one of the least used configurations in thermal power plants in Colombia. Finally, the thermal power plants that use double busbar configuration plus transfer switch contribute with 6.34% of the generating capacity in terms of reliability and flexibility indicators, it is the least used in thermal power plants in Colombia because their equipment requires a large area for its implementation.

5. CONCLUSION

The paper established the definition of configuration in substations required in generation units, focusing results on to identify the thermal district of Colombia where the electricity is produced by thermal power plants. It was determined that the thermal power plants in Colombia with declared generation capacity are a group of 18 companies in different departments of the country with a generation capacity of 5329.1 MVA contributed to the interconnected system. Using the Hirschman Herfindahl index (HHI), it was identified that the department with the largest declared generation capacity is Atlántico, with a 1,521 MVA installed capacity. This is equal to 28.54% of Colombia’s thermal generation capacity and occupying the 9.42% of the declared energy capacity among the other electricity generation processes in Colombia.

In Colombia, the most used configuration of substation to connect thermal power plants is one-and-a-half configuration. It has a 39.74% of participation to connect power plants units providing security and reliability. Also, a flexible operation avoiding bars contingencies or operation factor that affect bars. There are single bars supporting thermal power plants which in a percent equal to 21.94%, so this is not reliable, secure, or flexible against contingencies, operational changes or maintenances affecting availability most times and compromising the total system operation against a total blackout which is an aspect to be improved. Contribution and future trends of the paper are guided towards planners and utilities to use market index HHI to identify market concentration and guarantee an accurate distribution of units to support constraints in areas. Evaluating capacities versus configuration helps to identify concentration level of configurations to know the total reliability, security, and flexibility of the system, which helps planners and utilities to promote improvements in the system.

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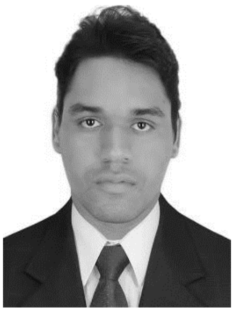

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