POWER TRANSFORMERS AND EMERGENCY GENERATOR SETS

Sizing

INDEX PÁG.

1 PURPOSE

The purpose of this technical information is to define criteria for the sizing of power transformers and emergency generating sets, of hydroelectric power plant installations, to meet electrical auxiliary systems.

This text is written specifically for application in auxiliary services of hydroelectric plants, with vertical generating units activated by Francis turbines, but can be applied to other types of power plant installations, or other type of installations, provided that adjustments are made to the type of application considered.

2 REFERENCE DOCUMENTS

2.1 Technical Information

IT.EL.SA.CA.01.R1 Rated Voltage and Voltage Variations

2.2 Spreadsheets

TE.EL.SA.AC.01.R1 POWER TRANSFORMERS - Voltage Calculation in the Terminals

PL.EL.SA.CA.02.R1 DIESEL GENERATORS SETS - Calculations of Transient Reactance

PL.EL.SA.CA.03.R1 DIESEL GENERATORS SETS - Calculations of Terminals Voltage

3 INITIAL CONSIDERATIONS

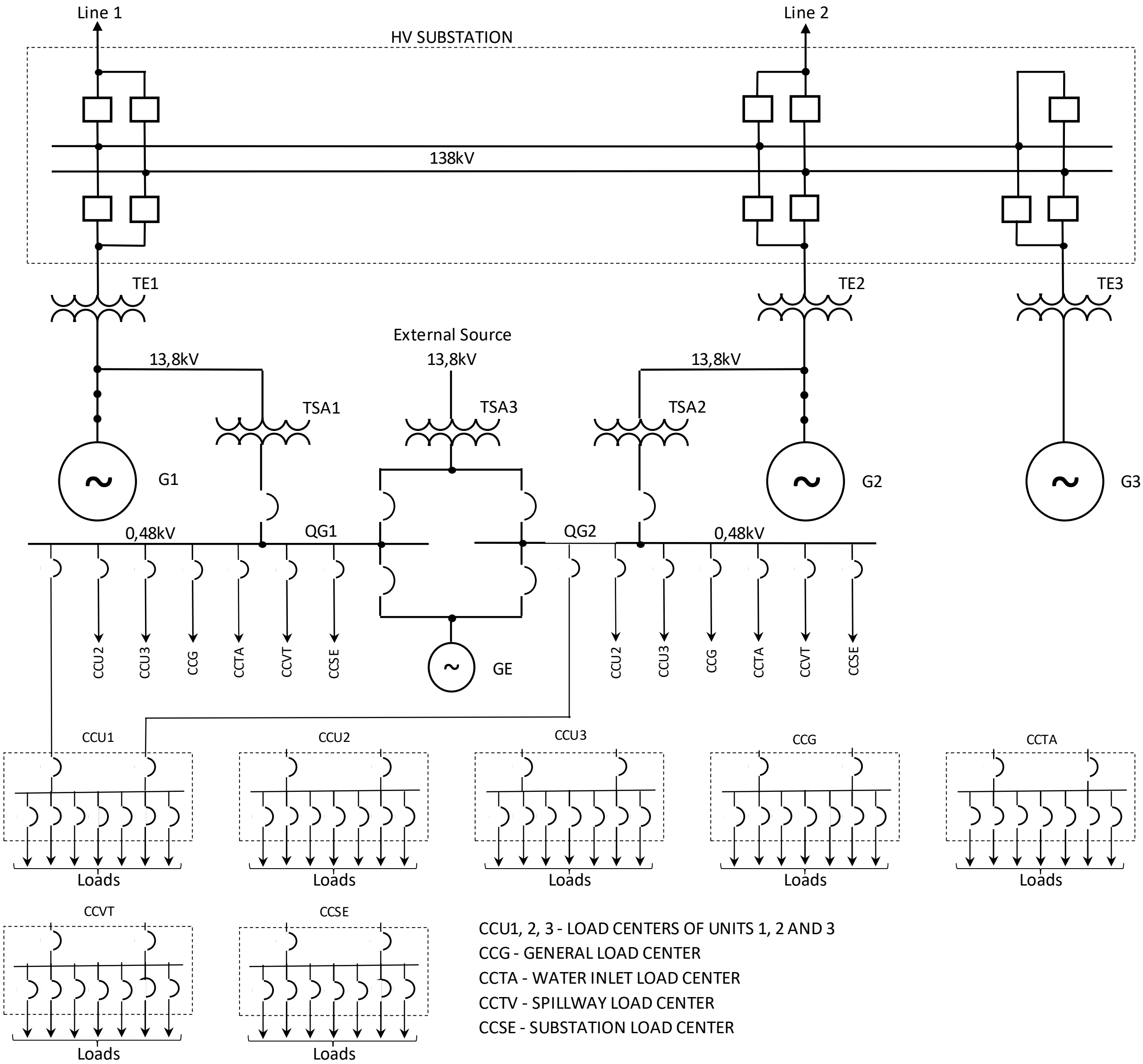
The definition of rated electrical powers and equipment characteristics (transformers, generator sets, load centers, distribution boards, etc.) depends on the knowledge of the installation loads and their operating conditions. Therefore, the professional who intends to define these values should have this knowledge and, if necessary, count on the support of professionals from other areas to carry out this task.

The configuration of the electrical system of a hydroelectric power plant, as well as industrial installations, is usually a definition that depends on several factors such as customer standards, purpose, and size of the installation, interconnected electrical system, etc. For this technical information, the configuration of the diagram below will be considered, as it allows the understanding of the need to have sufficient knowledge to apply it in other configurations, including in industrial installations, with the respective adjustments.

There are hydroelectric power plants with units driven by Francis, Pelton and Kaplan turbines. However, as mentioned at the beginning, this work will be limited to vertical units driven by Francis turbines.

To size the auxiliary service transformers and the emergency generator diesel set, it is necessary to know the loads, purposes, operating conditions, and powers.

The configuration of the following diagram, which will serve for the development of the reasoning of this technical information, consists of three generating units (G1, G2 and G3), which provide power to the high voltage system, through the step-up transformers (TE1, TE2 and TE3) and the HV Substation in 138kV (in this case, double bar).



Auxiliary services electrical are feed by two units (G1 and G2), through auxiliary services transformers (TSA1 and TSA2), in emergency conditions by the emergency generator diesel set (GE) and, occasionally, by the external source, through the transformer (TSA3). The external source could have been omitted because the auxiliary services system could also be fed, during long periods of power outage, by the generating units (G1 and G2), by the high voltage system, through the step-up transformers (TE1/TSA1 or TE2/TSA2) if means are installed to isolate the generating units (G1 and G2).

The loads of the power plant are fed by the general load centers (QG1 and QG2), through the load centers distributed by the plant (CCU1, CCU2, CCU3, CCG, CCTA, CCVT and CCSE).

4 ELECTRIC LOADS

The electrical loads of an installation have the purpose of serving equipment and installations that, depending on their importance, have redundant equipment to avoid the stop of the unit(s) due to failures or maintenance. Power plant loads can be classified as continuous, intermittent, and sporadic.

Continuous: these are the loads that operates uninterruptedly to meet the needs of the installation. For example, oil circulation pumps of generator’s thrust and guide bearing, oil circulation pumps of turbine's guide bearing, powerhouse ventilation and exhaust systems, unit cooling water system, etc.

Intermittent: are the loads that operates for limited periods, depending on the needs of the installation. For example, service air compressors, drainage pumps, etc.

Sporadic: are the loads that operates for limited time periods, in certain specific situations of power plant operation. For example, fire pumps, overhead crane, depletion pumps, oil treatment system etc.

The classification of loads can be done with ease when the installations, equipment and their operating conditions are known.

In hydroelectric power plants the operating conditions to be considered are:

Normal: This condition considers all generating units in operation. In this condition, in addition to permanent loads, loads that can be used with all units in operation should be considered, such as:

- The Insulating oil treatment system of Step-Up Transformers, which according to the operating and maintenance criteria can possibly be used in the spare elevator transformer, when it exists, and even in transformers that are in operation.

- Lifting and handling cargo equipment's, such as overhead crane, rolling gantries, electric hoist, etc., which can also be used during the operation of all units because, even without using the maximum lifting and translation capacities, they are used for routine services.

Maintenance: This condition typically considers one unit under maintenance and the others in operation. In this condition, in addition to the loads of the units that remain in operation, the loads that operate specifically in this situation should be considered, such as:

- Depletion Pumps of Draft Tube.
- The Lubricating Oil Treatment System.
- Generator Heating Resistors
- Overhead crane and rolling gantries.

Emergency: this condition occurs with the loose of power from the sources of The TSA1, TSA2 and TSA3, associated with the stop of the generating units. At this stage, the emergency diesel set goes into operation keeping the important systems up and running. The degraded operation of the installation is followed by the start of one of the generating units, to restore the normal condition of the system. The reinstatement is carried out by the diesel emergency generator set, which will be responsible for feeding the loads of the electrical auxiliary systems.

4.1 Definition of Installation Loads

To size the system components, it is necessary to relate the electrical loads, define their powers and operating conditions. Load data must be defined by the specialists of each equipment or installation, based on the information of the project and/or equipment manufacturers.

For the case of hydroelectric plants, which are considered in this document, the loads and their powers also depend on the size of the installation.

4.2 Estimated Powers

The load powers are defined by the specialists of each equipment or installation. However, when this information is not yet defined by manufacturers, it is necessary to estimate it, based on the project data.

The following are provided, by way of illustration, some practical criteria for estimating the potencies of some of the most common equipment:

4.2.1 Pumps

The motor power of a pump can be estimated considering that the sizing of the pump is done using the following formula:

$$P_{(kW)} = \frac{Q\ .h.\rho}{3{,}67\ x\ \eta}$$

Where:

$P_{(kW)}$- Power required by the pump (kW)

Q - Pump flow (m^3/h)

h- Manometric height (mca)

ρ- Liquid density (for water equal to 1.0)

η - Pump performance (%)

As flow and manometric height are usually known, can be adopt η=80%.

According to API 610 recommendations, the motor should be chosen according to the table below:

Table 12 — Power ratings for motor drives

Motor nameplate rating		Percentage of rated pump power
kW	hp	%
< 22	< 30	125
22 to 55	30 to 75	115
> 55	> 75	110

That is:

For a pump with a water flow rate of 75m^3/h and a manometric height of 60m, the power required by the pump will be:

$$P_{(kW)} = \frac{75\ x\ 60\ x\ 1{,}0}{3{,}67\ x\ 80} = 15{,}33kW$$

Therefore, considering the percentage of API 610, the rated power of the motor should be 125% of the power absorbed by the pump, i.e.:

$$P_{motor\,(kW)} = 15{,}33\ x\ 1{,}25 = 19{,}16kW$$

The motor that will be considered will be the motor with immediately above standardized power, i.e., 22kW (30 hp).

4.2.2 Compressors

Service Air Compressors are typically manufacturer-standardized equipment, and the best solution is to use available catalog data based on information on installation needs.

Specific compressors, such as Compressors of Turbine Speed Governor, are defined by the turbine manufacturer and, when their power is not available, should be estimated by the specialist of the equipment or installation.

4.2.3 Lifting and Handling Cargo Equipment

Lifting and handling cargo equipment can only be operated with one movement at a time, i.e., translation, steering or lifting. However, as the highest load is from lifting, we can consider that the formula to be used is:

$$Power(cv) = \frac{C\ x\ v\ x\ 100}{75\eta} f_s$$

Where:

C Load to be lifted (kg)

v Lifting speed (m/s)

η Equipment performance (%)

f_s Safety factor

In the absence of data consider the equipment performance 80% and adopt an safety factor of 1.2.

A overhead crane to lift a load of 90t at a maximum speed of 3m/min (0.05m/s) must have an approximate power of:

$$Power(cv) = \frac{C\ x\ v\ x\ 100}{75\eta} f_s = \frac{90000\ x\ 0{,}05\ x\ 100}{75.80} 1{,}2 = 90\ cv$$

The motor that will be considered will be the motor with immediately higher standardized power, i.e., 100 hp.

5 LOADS OF THE POWER PLANT

The following are the loads normally found in hydroelectric power plants, with a view to the sizing of auxiliary services transformers and emergency generator diesel set.

Depending on the quantity and power of the generating units, may be an increase, reduction or variation in the powers and quantity of loads, which must be subject to adequacy, but do not alter the purpose of this document. The definition of the loads, type and operating conditions are described to characterize the need for and importance of knowledge, which the specialist responsible for the sizing of the facilities must have, to correctly size the transformers of auxiliary services and emergency generator diesel set.

5.1 Generating Units

Each generating unit typically has the following loads:

5.1.1 Oil Pumps of Turbine’s Speed Governor

These pumps are part of the turbine’s speed governor drive system. There are usually at least two pumps, one main, which runs continuously, and another reserve.

5.1.2 Oil Circulation Pumps of Generator’s Thrust and Guide Bearing

These pumps have the function of keeping lubricated the combined bearing, of thrust and guide, of the generator. These pumps operate throughout the starting process of the generating unit until total stop. There are two pumps, one main and one reserve.

5.1.3 Oil Circulation Pumps of Turbine’s Guide Bearing

These pumps have the function of keeping the turbine’s guide bearing lubricated. These pumps operate throughout the starting process of the generating unit until total stop. There are two pumps, one main and one reserve.

5.1.4 Oil Injection Pumps of Thrust Bearing

This pump has the function of creating an oil film in the thrust bearing, to allow the start of the unit. This pump works only at the beginning of the start and end of the unit's stop, but exceptionally, for example, in the case of lack of electrical power, the unit can be stopped without the oil injection pump.

Some older units do not have the oil injection system. However, when the unit is stopped for a certain time, to put the unit in operation, the creation of the oil film in the thrust bearing is done by the braking system, through the rotor lifting pump.

5.1.5 Turbine Cover Draining Pumps

These pumps have the function of draining the water that leaks through the seal of the turbine shaft. These pumps operate intermittently. Usually there are two pumps, a main one and a reserve.

5.1.6 Generator Heating Resistors

The generator well heating resistors are intended to prevent moisture in the generator windings. These resistors operate only when the unit is stationary or under maintenance.

5.1.7 Turbine Well Oil Steam Exhauster

This exhauster has the purpose of removing, from the environment of the turbine well, the oil steam released by the bearings of the generating unit. These exhaust fans operate continuously.

5.1.8 Pumps or Valve of Unit Cooling Water System

Depending on the pressure of the forced conduit, it is sometimes more convenient to perform cooling in the air-to-water heat exchangers of the generator stator and in the oil-water heat exchangers of the lubrication systems of the unit's bearings, using downstream water from the plant. This cooling is done by pumps that operate throughout the period of operation of the generating units. Depending on the definition, a pumps system can serve more than one generating unit.

When cooling water is obtained directly from the forced conduit of the units, the circulation of the water is made by opening a valve, usually motorized. The opening of the valve is done to establish the cooling system and allow the start of the generating unit. Its closure is done after the total shutdown of the generating unit.

5.1.9 Generator Excitation Cubicle

The load of the excitation cubicle the generator, which is part of the load to be considered in the design of auxiliary service transformers and emergency generator diesel set, consists of the supply of the transformer of the initial excitation of the generator (Field Flash). This load only operates at the end of the unit's departure and lasts only a few seconds.

5.1.10 Auxiliaries of Step-Up Transformer

The auxiliary loads of the step-up transformers, which can be part of the forced cooling systems are, depending on the size of the transformers: forced ventilation, forced circulation of insulating oil, forced circulation of water or other similar loads that are necessary. These loads work throughout the period of operation of the generating units and, after the shutdown, until the temperature of the systems served allows their stopped.

5.1.11 Cooling Water System Self-Cleaning Filter

The self-cleaning filter motor operates intermittently whenever the differential pressure switch detects that the filter is dirty.

5.2 Powerhouse

The loads of the powerhouse, common to all units are:

5.2.1 Drainage Pumps

The drainage system consists of two or more pumps, designed to pump the percolation and service water used in the powerhouse, to the discharge channel. In this system two pumps are used, one main and one reserve. The main pump works intermittently and the standby pump normally only in exceptional cases, such as in case of fire.

5.2.2 Air Compressors of Speed Governor

The compressed air system of the speed governors is usually composed of a set of two compressors and a high-pressure air reservoir, which supply the speed regulation systems of the three turbines. The compressors operate intermittently, one main and one reserve.

5.2.3 Ventilation and Exhaust System

The ventilation and exhaust system has the function of maintaining the temperature in the environments of the powerhouse within values defined in the project, ensuring thermal comfort, health, and safety of people. The number of fans and exhausters of the system depends on the size and physical arrangement of the powerhouse. The operation of the fans and exhaust fans of the system is continuous, and few equipment have reserves such as, for example, the ventilation and exhaust systems of battery rooms. In battery rooms, with ventilated type batteries, ventilation and exhaust are intended to dilute the concentration of hydrogen produced by batteries to avoid the risk of explosion.

5.2.4 Air Conditioning System

The air conditioning system has the function of giving thermal comfort to people who work in confined environments and maintain the temperature in environments that have equipment that requires air conditioning. In hydroelectric plants these environments are the control rooms, sealed battery rooms and offices. The amount of equipment depends on the amount and size of the environments that require air conditioning. The operation of the systems is continuous and have main equipment and reserves.

5.2.5 Service Air Compressors

The plant's service air system consists of two compressors, which accumulate air in a reservoir that supplies air throughout the facility, including the individual reservoirs of the braking system of the generating units. The compressors operate intermittently, with one main compressor and one reserve.

5.2.6 Telecommunications System

The charge of the telecommunications system consists of battery chargers of the telecommunications system. This load is a constant load and has redundancy, in the same way as the direct current system of the powerhouse.

5.2.7 Battery Chargers

The battery chargers have the function of charging and keeping charged the batteries of the direct current systems of the plant. Due to the importance of the systems, there are at least two sets of chargers and batteries. The two chargers operate continuously in a floating regime, that is, they keep the batteries charged and feed the direct current consumption of the plant. When the batteries discharge, the chargers start to charge the batteries and are sized to, simultaneously, feed the direct current charges of the plant.

5.2.8 Lighting and Heating Transformers

The lighting and heating transformers have the function of meeting the loads of the lighting and heating installations of the plant. The quantity and power of these transformers depends on the size of the installation configuration. These transformers operate continuously with a load that can be reduced at night.

5.2.9 People Lift

Due to the arrangement of the powerhouse, it may be necessary to install an elevator to transport people.

5.2.10 Auxiliaries of the Diesel Emergency Generator Set

The load of the emergency diesel set auxiliaries consists of the set of accessories necessary to keep the diesel group ready to depart. These loads are, control transformer, engine preheater and fuel transfer pump.

5.2.11 Rotor Lifting System Pump

The rotor braking and lifting system consists of an air and oil system. The air is obtained from the powerhouse service air system, which is stored in the unit's tank, specific to the braking system. The oil for lifting the rotor is pumped by the braking system pump. The load of the braking and lifting system, for the purpose of electric loads, consists only of the oil pump. Typically, there is a single rotor lifting system that serves all units. This system is used, when necessary, during the maintenance services of the units.

5.2.12 Depletion Pumps of Draft Tube

The depletion system consists of pumps designed to deplete water from the penstock, spiral turbine box and draft tube of the generating unit. This system only operates when it is necessary to perform maintenance services on the turbine and is usually made up of two pumps, which can run simultaneously, to reduce depletion time.

5.2.13 Fire Fighting Pumps

The firefighting system consists of two pumps intended to fight the fire in the premises. This system is usually provided with two pumps, one main and one reserve. In some installations the backup pump is driven by diesel engine.

5.2.14 Overhead Crane

The overhead crane of the powerhouse has the purpose of moving all equipment and loads, being sized to move the heaviest load of the plant, which is the rotor of the generator. Despite being sized to lift the rotor of the generator with the maximum speed, it is much more used to move smaller loads. The loads of a main overhead crane are lifting, steering and translation.

5.2.15 Power Outlets

The power outlets are distributed throughout the installation, to meet the loads necessary to perform services with heavier equipment such as welding machines, compressors, mobile oil treatment systems, etc.

5.2.16 Mobile Insulating Oil and Lubricating Oil Treatment Systems

Insulating oil and lubricating oil treatment systems are usually portable units that are connected to the power take-offs near the equipment that will be served.

5.2.17 Downstream Rolling Gantry

The loads of the downstream rolling gantry are those necessary to perform the maintenance services, placement and removal of the stop logs of the draft tubes of the units, which allow the emptying of the penstock, spiral case and draft tube of the unit in which the maintenance is to be carried out. These loads are the lifting winch, direction and translation of the gantry.

5.3 Water intake

The water intake loads consist, in addition to some power outlets and lighting panels, of the following relevant loads:

5.3.1 Upstream Rolling Gantry

The loads of the upstream rolling gantry are those necessary for the maintenance services of the stop logs and gates of the water intake of the units. These loads are the lifting, steering and translation of rolling gantry and, in some cases, cleaning grilles machine.

5.3.2 Hydraulic Power Unit of the Water Intake Gates

The gates of the water intake maintain the water flow of the generating units. The gates open to allow the unit to start and remain open even when the units are stopped. Each generating unit has its gate or set of gates, which are closed in case of emergency or for maintenance.

The gates are driven by a hydraulic system, which can serve multiple units. The system has a hydraulic power unit, equipped with two oil pumps, a main and a reserve. One of the pumps works when it is necessary to open one gate or when it is necessary to restore its position. The restore of position of the gate is a sporadic operation, which occurs due to small leaks in the hydraulic system, which activates the gate position sensor.

5.4 Spillway

The spillway loads consist, in addition to some power take-offs and lighting panels, of the following relevant loads:

5.4.1 Spillway Rolling Gantry

The loads of the spillway rolling gantry are those necessary for the maintenance services of the stop logs and the spillway gates. These loads are the lifting winch, steering and translation.

5.4.2 Hydraulic Power Unit of the Spillway Gates

The spillway gates serve to drain the excess water accumulated in the reservoir or to maintain the minimum flow of the river when there is a problem at the plant. Due to their purpose these gates are rarely activated and, when they are, they operate one by one and to maintain a small opening for the passage of water.

The gates are driven by a hydraulic system, which can serve more than one unit. The system has a hydraulic power unit, equipped with two oil pumps, a main and a reserve. One of the pumps works when it is necessary to open a gate or when it is necessary to replenish the position of the gate. The replacement of the gate is a sporadic operation, which occurs due to small leaks in the hydraulic system, which causes the activation of the gate position sensor.

5.5 HV Substation

The load of a substation basically consists of power take-offs, lighting and the drive of disconnecting switches and compressors of the circuit breakers of the high voltage system.

In large power plants, low-voltage electrical installations are powered by dedicated transformers, which can be sized based on the same concepts used here.

6 DEFINITION OF LOADS

For the definition of the necessary powers of auxiliary services transformers and emergency generator diesel group it is necessary, based on the knowledge of the operation, use and operating conditions of the loads, to define the consumption of the installations in each situation of operation of the plant.

To consolidate the concepts of this document, the loads of a power plant composed of 3 generating units and an associated small substation, will be considered, as represented in the single-line diagram represented at the beginning of this document. All the loads used in this simulation are estimated and have the purpose of illustrating the definition of consumption.

For lifting and handling loads, it will be considered that only one movement is made at a time. Therefore, only the largest loads, which are those of the main winches, will be considered.

6.1 Generating Units

The following are related the specific loads of the generating units of the plant and applied the considerations about their operation and operating conditions. In the list below are indicated the loads that will be considered, for each unit.

6.1.1 Oil Pumps of Turbine’s Speed Governor

Two pumps driven by 100 hp motors will be considered, one main and one reserve.

6.1.2 Oil Circulation Pumps of Generator’s Thrust and Guide Bearing

Two pumps driven by 10 hp motors will be considered, one main and the other reserve.

6.1.3 Oil Circulation Pumps of Turbine’s Guide Bearing

Two pumps driven by 7.5 hp motors will be considered, one main and one reserve.

6.1.4 Oil Injection Pumps of Thrust Bearing

Two pumps driven by 15 hp motors will be considered, one main and one reserve.

6.1.5 Turbine Cover Draining Pumps

Two pumps driven by 3 hp motors will be considered, one main and one reserve.

6.1.6 Generator Heating Resistors

Generator heating resistors with a total power of 15 kW will be considered.

6.1.7 Turbine Well Oil Steam Exhauster

It will be considered an exhaust fan driven by a 0.5 hp motor.

6.1.8 Unit Cooling Water Valve

It will be considered a motorized valve driven by a 1.5 hp motor.

6.1.9 Generator Excitation Cubicle

It will be considered an initial excitation transformer (Field Flash) of 10 kVA.

6.1.10 Auxiliaries of Step-Up Transformer

It will be considered a set of fans, driven by motors, totaling a power of 30 kVA.

6.1.11 Cooling Water System Self-Cleaning Filter

The self-cleaning filter motor will be considered with power of 1.5 hp.

6.2 Powerhouse

The following are related to the common loads of the powerhouse and applied the considerations about their operating conditions. In the list below are indicated the loads that will be considered.

6.2.1 Drainage Pumps

Two pumps driven by 20 hp motors will be considered, one main and one reserve.

6.2.2 Air Compressors of Speed Governor

Two compressors driven by 30 hp motors will be considered, one main and one reserve.

6.2.3 Ventilation and Exhaust System

It will be considered a set of inflating fans and exhaust fans, driven by motors, totaling a power of 75 hp.

6.2.4 Air Conditioning System

It will be considered a set of conditioning equipment, totaling a continuous power of 30 hp.

6.2.5 Service Air Compressors

Two compressors driven by 15 hp motors will be considered, one main and one reserve.

6.2.6 Telecommunications System

It will be considered a telecommunications system with total continuous consumption of 10 kVA.

6.2.7 Battery Chargers

Two battery chargers will be considered, each with a rated power of 15 kVA, with a permanent consumption of 5 kVA total, in a floating regime.

6.2.8 Lighting and Heating Transformers

A total of 6 lighting and heating transformers will be considered, each with a rated power of 10 kVA, to feed the loads of the powerhouse. The total consumption of the transformer set will be 30 kVA.

6.2.9 People Lift

It will be considered a lift with sporadic consumption of 7.5 kVA.

6.2.10 Auxiliaries of the Diesel Emergency Generator Set

A total continuous consumption of 1.5 kVA will be considered.

6.2.11 Rotor Lifting System Pump

It will be considered a pump driven by a 3 hp motor for lifting the rotor of the unit.

6.2.12 Depletion Pumps of Draft Tube

Two pumps driven by 30 hp motors will be considered, and both pumps can operate simultaneously.

6.2.13 Fire Fighting Pumps

Two pumps driven by 40 hp engines will be considered, one main and one reserve.

6.2.14 Overhead Crane

Will be considered only the power of the main winch with a power of 75 hp, which operates at a maximum load only during the maintenance period, for the lifting of the generator rotor of the unit and, at other times, with an arbitrated power of 20 kVA to move smaller loads.

Although the overhead crane winch meets the highest load of the plant and is sized to lift the generator rotor at maximum speed, this operation occurs rarely and only when it is necessary to assemble and disassemble the unit. However, when it occurs, because it is a delicate operation and involves a vital part, hardly the lifting of the rotor is done with maximum speed, on the contrary, this operation is done with all care, in short intervals of operation (a few minutes) and low speeds.

6.2.15 Power Outlets

It will be considered a set of 10 power outlets distributed by the powerhouse, with individual power of 30 kVA and total sporadic consumption of 30 kVA, during the normal operation of the plant and, 60 kVA, also sporadic, during the maintenance services of a unit.

6.2.16 Mobile Insulating Oil Treatment System

The mobile insulating oil treatment system will be considered as a sporadic load of 60 kVA, during the maintenance services of a generating unit or maintenance of a backup transformer, which we will consider existing.

6.2.17 Mobile Lubricating Oil Treatment System

The mobile lubricating oil treatment system will be considered as a sporadic load of 30 kVA during the maintenance services of a generating unit.

6.2.18 Downstream Rolling Gantry

Only the main winch of the rolling gantry will be considered, with sporadic power of 15 hp, which can operate in case of maintenance.

6.3 Water Intake

The following are related the specific loads of the water intake with considerations about its operation conditions. In the list below are indicated the loads that will be considered.

6.3.1 Lighting and Heating Transformer

It will be considered a single lighting and heating transformer, with a rated power of 10 kVA. The continuous consumption considered will be 5kVA.

6.3.2 Power Outlet

2 power outlets, with an individual power of 30 kVA and sporadic consumption of 15 kVA, will be considered during maintenance services.

6.3.3 Upstream Rolling Gantry

Only the main winch of the rolling gantry will be considered, with sporadic power of 20 hp, which can operate in case of maintenance.

6.3.4 Pumps of the Hydraulic Power Unit of the Water Intake Gates

Two pumps driven by 15 hp motors will be considered, with sporadic operation, one main and the other reserve.

6.4 Spillway

The following are related to the specific loads of the spillway, with considerations about its operation conditions. In the list below are indicated the loads that will be considered.

6.4.1 Lighting and Heating Transformer

It will be considered a single lighting and heating transformer, with a rated power of 10 kVA. The continuous consumption considered will be 5kVA.

6.4.2 Power Outlet

2 power outlets, with an individual power of 30 kVA and sporadic consumption of 15 kVA, will be considered during maintenance services.

6.4.3 Spillway Rolling Gantry

Only the main winch of the rolling gantry will be considered, with sporadic power of 15 hp, which can operate in case of maintenance.

6.4.4 Pumps of the Spillway Gates Hydraulic Power Unit

Two pumps driven by 7.5 hp motors will be considered, with sporadic operation, one main and the other reserve.

6.5 HV Substation

The following are the specific loads of the high voltage substation, with considerations for its operation conditions. In the list below are indicated the loads that will be considered.

6.5.1 Lighting and Heating Transformer

It will be considered a single lighting and heating transformer, with a rated power of 10 kVA. The continuous consumption considered will be 5kVA.

6.5.2 Power Outlet

2 power outlets, with an individual power of 30 kVA and sporadic consumption of 15 kVA, will be considered during maintenance services.

6.5.3 Switches and Circuit Breakers

As the loads of a substation refer to the drive of circuit breakers and disconnectors, an installed load of 30 kVA with a sporadic consumption of 5 kVA will be considered, since the switches and circuit breakers are triggered one at a time.

7 CALCULATION OF CONSUMPTIONS

To facilitate the calculation of consumptions, the loads will be indicated in tables containing their information and operating conditions.

Under normal conditions, the start-up and shutdown of a unit are operations that take minutes, the operation of the units many months, and maintenance a few days or weeks.

In the calculations the following approximation will be used:

1cv=1hp=1kW=1kVA

Legend used in tables:

Continuous Load

Intemittent Load

Sporadic Load

7.1 Loads of the Units

The following table shows the loads of one unit:

LOADS OF ONE UNIT									
CARGO DESCRIPTION	POWER								
	REAL	kVA							
		INSTALLED	START OF OPERATION	STARTING	OPERATION END	OPERATING	STOPPING	STOP'S END	STOPPED
Oil Pumps of Turbine's Speed Governor (2)	100 cv	200	100	100	100	100	100	100	
Oil Circulation Pumps of Generator's Thrust and Guide Bearing (2)	10 cv	20	10	10	10	10	10	10	
Oil Circulation Pumps of Turbine's Guide Bearing (2)	7,5 cv	15	7,5	7,5	7,5	7,5	7,5	7,5	
Oil Injection Pumps of Thrust Bearing (2)	15 cv	30	15	15			15	15	
Turbine Cover Draining Pumps (2)	3 cv	6	3	3	3	3	3	3	3
Generator Heating Resistors (1)	15 kW	15							15
Turbine Well Oil Steam Exhauster (1)	0,5 cv	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Pumps or Valve of Unit Cooling Water System (1)	1,5 cv	1,5	1,5					1,5	
Generator Excitation Cubicle (1)	10 kVA	10			10				
Auxiliaries of Step-Up Transformer (1)	30 kVA	30	30	30	30	30	30	30	
Cooling Water System Self-Cleaning Filter (1)	1,5 cv	1,5	1,5	1,5	1,5	1,5	1,5	1,5	
CONTINUOUS TOTAL (kVA)	**-**	**-**	**164,5**	**163,0**	**158,0**	**148,0**	**163,0**	**164,5**	**15,5**
INTERMITTENT TOTAL (kVA)	**-**	**-**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
SPORADIC TOTAL (kVA)	**-**	**-**	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**	**0**
GRAND TOTAL (kVA)	**-**	**329,5**	**169,0**	**167,5**	**162,5**	**152,5**	**167,5**	**169,5**	**18,5**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

7.2 Powerhouse Loads

The following data are related to Powerhouse Loads and applied considerations about their operation conditions. The normal condition considers the three units in operation, the maintenance condition considers only one unit in maintenance and the emergency condition, the three units stopped, without power in the three auxiliary services transformers.

POWERHOUSE LOADS						
CARGO DESCRIPTION	POWER					
	REAL	kVA				
		INSTALLED	NORMAL OPERATION	MAINTENANCE	EMERGENCY
Drainage Pumps (2)	20 cv	40	20	20	20
Air Compressors of Speed Governor (2)	30 cv	60	30	30	30
Ventilation and Exhaust System (1 Set)	75 cv	75	75	75	10
Air Conditioning System (2)	30 cv	60	30	30	15
Service Air Compressors (2)	15 cv	30	15	15	15
Telecommunications System (2)	10 kVA	20	10	10	10
Battery Chargers (2)	15 kVA	30	5	5	5
Lighting and Heating Transformers (6)	10 kVA	60	30	30	30
People Lift (1)	7,5 kVA	7,5	7,5	7,5	7,5
Auxiliaries of the Diesel Emergency Generator Set (1)	1,5 kVA	1,5	1,5	1,5	1,5
Rotor Lifting System Pump (1)	3 cv	3		3	
Depletion Pumps of Draft Tube (2)	30 cv	60		60	
Fire Fighting Pumps (2)	50 cv	100	50	50	50
Overhead Crane (1)	75 cv	75	20	20	
Power Outlets (10)	30 kVA	300	30	60	
Mobile Insulating Oil Treatment System (1)	60 kVA	60	60	60	
Mobile Lubricating Oil Treatment System (1)	30 kVA	30		30	
Downstream Rolling Gantry (1)	15 kVA	15		15	
CONTINUOUS TOTAL (kVA)	**-**	**-**	**151,5**	**151,5**	**71,5**
INTERMITTENT TOTAL (kVA)	**-**	**-**	**65,0**	**65,0**	**65,0**
SPORADIC TOTAL (kVA)	**-**	**-**	**167,5**	**305,5**	**57,5**
GRAND TOTAL (kVA)	**-**	**1027,0**	**384,0**	**522,0**	**194,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

7.3 Water Intake Loads

The following are related the loads of the water intake and applied the considerations about its operation conditions.

WATER INTAKE LOADS						
CARGO DESCRIPTION	POWER					
	REAL	kVA				
		INSTALLED	NORMAL OPERATION	MAINTENANCE	EMERGENCY
Lighting and Heating Transformers (1)	10 kVA	10	5	5	5
Power Outlets (2)	30 kVA	60	15	15	
Upstream Rolling Gantry (1)	20 cv	20		20	
Pumps of the Hydraulic Power Unit of the Water Intake Gates (2)	15 cv	30	15	15	15
CONTINUOUS TOTAL (kVA)	**-**	**-**	**5,0**	**5,0**	**5,0**
INTERMITTENT TOTAL (kVA)	**-**	**-**	**0**	**0**	**0**
SPORADIC TOTAL (kVA)	**-**	**-**	**30,0**	**50,0**	**15,0**
GRAND TOTAL (kVA)	**-**	**120,0**	**35,0**	**55,0**	**20,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

7.4 Spillway Loads

The following are related to the loads of the spillway and applied considerations about its operation conditions.

SPILLWAY LOADS						
CARGO DESCRIPTION	POWER					
	REAL	kVA				
		INSTALLED	NORMAL OPERATION	MAINTENANCE	EMERGENCY
Lighting and Heating Transformers (1)	10 kVA	10	5	5	5
Power Outlets (2)	30 kVA	60	15	15	
Spillway Rolling Gantry (1)	15 cv	15		15	
Pumps of the Hydraulic Power Unit of the Spillway Gates (2)	7,5 cv	15	7,5	7,5	7,5
CONTINUOUS TOTAL (kVA)	**-**	**-**	**5,0**	**5,0**	**5,0**
INTERMITTENT TOTAL (kVA)	**-**	**-**	**0**	**0**	**0**
SPORADIC TOTAL (kVA)	**-**	**-**	**22,5**	**37,5**	**7,5**
GRAND TOTAL (kVA)	**-**	**100,0**	**27,5**	**42,5**	**12,5**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

7.5 HV Substation Loads

The following are related the loads of the High Voltage Substation and applied considerations about its operation conditions.

HV SUBSTATION LOADS						
CARGO DESCRIPTION	POWER					
	REAL	kVA				
		INSTALLED	NORMAL OPERATION	MAINTENANCE	EMERGENCY
Lighting and Heating Transformers (1)	10 kVA	10	5	5	5
Power Outlets (2)	30 kVA	60	10	10	
Motors of Switches and Circuit Breakers (1 Set)	30 cv	30	5	5	5
CONTINUOUS TOTAL (kVA)	**-**	**-**	**5,0**	**5,0**	**5,0**
INTERMITTENT TOTAL (kVA)	**-**	**-**	**0**	**0**	**0**
SPORADIC TOTAL (kVA)	**-**	**-**	**15,0**	**15,0**	**5,0**
GRAND TOTAL (kVA)	**-**	**100,0**	**20,0**	**20,0**	**10,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

8 TRANSFORMERS

The minimum rated power of a transformer shall meet the continuous consumption and consumption of the simultaneous operation of intermittent and sporadic loads of the installation, under normal operating or maintenance conditions.

The difficulty of sizing transformers consists in defining the simultaneity of operation of intermittent and sporadic loads, as well as their operating time. Some of these loads can operate for long periods, such as oil treatment systems; others for very short periods, on the order of minutes, as is the case of cranes, rolling gantries, lift, and hydraulic gate power stations. Therefore, the definition of the loads that should be considered must be made based on the knowledge of the facilities.

The loads of the plant's auxiliary services are fed by the TSA1 and TSA2 transformers, and each transformer is sized to power the entire installation in any operating condition. In this way, each transformer would meet 50% of the load of the plant and, in the event of failure in one of them, the other transformer takes over the entire load.

The powers of the transformers are defined at the beginning of the project, that is, still with estimated data of the loads. Depending on design criteria, customer requirements, load uncertainties, forecast of expansions, etc., safety factors are applied in the sizing of the rated power of the transformers. Therefore, transformers normally operate at 50% of the actual load, which is less than the calculated nominal load.

For industrial and commercial installations, where the energy consumption occurs in defined load cycles, for periods of 24 hours, the sizing of the transformers can be done using the criterion of equivalent load, determined by the average square value of the load according to NBR 5146, ANSI C57.96, etc., that is:

$$\text{Equivalent Load} = \sqrt{\frac{S_1{}^2.t_1 + S_2{}^2.t_2 + S_3{}^2.t_3 \dots + S_n{}^2.t_n}{t_1 + t_2 + t_3 + \cdots + t_n}}$$

Where $S_{1,}$ $S_{2,}$ $S_{3,\dots..}$ $S_{n,}$ are the loads values and $t_{1,}$ $t_{2,}$ $t_{3,\dots}$ t_n the respective duration times.

It happens that, in hydroelectric plants, the operation of the loads is not cyclical. Therefore, the above criterion is not applicable, although there are many calculation memories using this criterion, considering a percentage of the value of intermittent and sporadic loads, and arbitrating a time of their operation. The following are briefly cited some examples, which are used in these memoirs, but their discussion will not be deepened because it is not considered applicable:

- To consider 50% of the rated power of the fire pump, operating 2 hours every 24 hours, does not correspond to reality. A fire pump will operate at 100% of the rated power, for as long as necessary, and will also involve the simultaneous operation of the plant's drainage pumps, including intermittent ones, which will drain the water pumped by the fire pumps.

- To consider 30% of the overhead crane rated power, operating 1 hour every 24 hours, is also not correct. The overhead crane is used when necessary and usually for short periods and with small loads. The highest load of the plant is the generator rotor, which is only hoisted during the assembly or disassembly of the generating unit(s), which occurs rarely and, because it is a delicate operation, is not done continuously nor with the maximum speed of the overhead crane.

- Considering 50% of the rated power of a depletion pump, operating 1 hour every 24 hours, does not correspond to reality. In case of need, the two depletion pumps will operate at 100% of the rated power, during the entire time foreseen to perform the exhaustion of the unit.

8.1 Data Analysis

To define the power of the transformers it is necessary to analyze and interpret the data from the tables and the operating conditions.

The most important analysis will be regarding the simultaneity of operation of the loads. However, once the impossibilities of the occurrence of the simultaneity of load operation are eliminated, the definition of the consumptions, in the various operating conditions of the plant, will not be difficult to define.

8.2 Normal Operation

In the normal operating condition of the plant will be considered the loads of the 3 generating units operating

8.2.1 Unit's Loads

The highest load, in the normal operating condition of the plant, can occur during the start or stop of a generating unit and with the other two units in operation. The simultaneous shutdown of all units occurs in case of lack of voltage in the plant and, in this case, the units must be able to stop, exceptionally, without the auxiliary systems of the units.

LOADS OF ONE UNIT									
CARGO DESCRIPTION	POWER								
	REAL	kVA							
		INSTALLED	START OF OPERATION	STARTING	OPERATION END	OPERATING	STOPPING	STOP'S END	STOPPED
Oil Pumps of Turbine's Speed Governor (2)	100 cv	200	100	100	100	100	100	100	
Oil Circulation Pumps of Generator's Thrust and Guide Bearing (2)	10 cv	20	10	10	10	10	10	10	
Oil Circulation Pumps of Turbine's Guide Bearing (2)	7,5 cv	15	7,5	7,5	7,5	7,5	7,5	7,5	
Oil Injection Pumps of Thrust Bearing (2)	15 cv	30	15	15			15	15	
Turbine Cover Draining Pumps (2)	3 cv	6	3	3	3	3	3	3	3
Generator Heating Resistors (1)	15 kW	15							15
Turbine Well Oil Steam Exhauster (1)	0,5 cv	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Pumps or Valve of Unit Cooling Water System (1)	1,5 cv	1,5	1,5					1,5	
Generator Excitation Cubicle (1)	10 kVA	10			10				
Auxiliaries of Step-Up Transformer (1)	30 kVA	30	30	30	30	30	30	30	
Cooling Water System Self-Cleaning Filter (1)	1,5 cv	1,5	1,5	1,5	1,5	1,5	1,5	1,5	
CONTINUOUS TOTAL (kVA)	**-**	**-**	**164,5**	**163,0**	**158,0**	**148,0**	**163,0**	**164,5**	**15,5**
INTERMITTENT TOTAL (kVA)	**-**	**-**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
SPORADIC TOTAL (kVA)	**-**	**-**	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**	**0**
GRAND TOTAL (kVA)	**-**	**329,5**	**169,0**	**167,5**	**162,5**	**152,5**	**167,5**	**169,5**	**18,5**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

The loads of the three units are indicated in the following table:

CARGO DESCRIPTION		POWER kVA					
		START OF OPERATION	STARTING	OPERATION END	OPERATING	STOPPING	STOP'S END
Unit 1 Starting or Stopping	**CONTINUOUS TOTAL**	**164,5**	**163,0**	**158,0**	**148,0**	**163,0**	**164,5**
	INTERMITTENT TOTAL	**3,0**	**3,0**	**3,0**	**3,0**	**3,0**	**3,0**
	TOTAL ESPORÁDICO	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**
Units 2 and 3 in Operation	**CONTINUOUS TOTAL**	**296,0**	**296,0**	**296,0**	**296,0**	**296,0**	**296,0**
	INTERMITTENT TOTAL	**6,0**	**6,0**	**6,0**	**6,0**	**6,0**	**6,0**
	TOTAL ESPORÁDICO	**3,0**	**3,0**	**3,0**	**3,0**	**3,0**	**3,0**
Total of 3 units	**CONTINUOUS TOTAL**	**460,5**	**459,0**	**454,0**	**444,0**	**459,0**	**460,5**
	INTERMITTENT TOTAL	**9,0**	**9,0**	**9,0**	**9,0**	**9,0**	**9,0**
	TOTAL ESPORÁDICO	**4,5**	**4,5**	**4,5**	**4,5**	**4,5**	**4,5**

8.2.2 Powerhouse Loads

The Powerhouse Loads, under normal operating conditions, which considers the three generating units in operation, are indicated below:

CARGO DESCRIPTION	POWER kVA
Drainage Pumps (2)	20
Air Compressors of Speed Governor (2)	30
Ventilation and Exhaust System (1 Set)	75
Air Conditioning System (2)	30
Service Air Compressors (2)	15
Telecommunications System (2)	10
Battery Chargers (2)	5
Lighting and Heating Transformers (6)	30
People Lift (1)	7,5
Auxiliaries of the Diesel Emergency Generator Set (1)	1,5
Fire Fighting Pumps (2)	50
Overhead Crane (1)	20
Power Outlets (10)	30
Mobile Insulating Oil Treatment System (1)	60
CONTINUOUS TOTAL (kVA)	**151,5**
INTERMITTENT TOTAL (kVA)	**65,0**
SPORADIC TOTAL (kVA)	**167,5**
GRAND TOTAL (kVA)	**384,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

8.2.3 Water Intake Loads

The loads of the water intake under normal operating conditions, which considers the three generating units in operation, are indicated below:

CARGO DESCRIPTION	POWER kVA
Lighting and Heating Transformers (1)	5
Power Outlets (2)	15
Pumps of the Hydraulic Power Unit of the Water Intake Gates (2)	15
CONTINUOUS TOTAL (kVA)	**5,0**
INTERMITTENT TOTAL (kVA)	**0**
SPORADIC TOTAL (kVA)	**30,0**
GRAND TOTAL (kVA)	**35,0**

8.2.4 Spillway Loads

The loads of the spillway, under normal operating conditions, which considers the three generating units in operation, are indicated below:

CARGO DESCRIPTION	POWER kVA
Lighting and Heating Transformers (1)	5
Power Outlets (2)	15
Pumps of the Hydraulic Power Unit of the Spillway Gates (2)	7,5
CONTINUOUS TOTAL (kVA)	**5,0**
INTERMITTENT TOTAL (kVA)	**0**
SPORADIC TOTAL (kVA)	**22,5**
GRAND TOTAL (kVA)	**27,5**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

8.2.5 HV Substation Loads

The loads of the high voltage substation, under normal operating conditions, which considers the three generating units in operation, are indicated below:

CARGO DESCRIPTION	POWER kVA
Lighting and Heating Transformers (1)	5
Power Outlets (2)	10
Motors of Switches and Circuit Breakers (1 Set)	5
CONTINUOUS TOTAL (kVA)	**5,0**
INTERMITTENT TOTAL (kVA)	**0**
SPORADIC TOTAL (kVA)	**15,0**
GRAND TOTAL (kVA)	**20,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

8.2.6 Summary

The summary of the loads of the plant, with the operation most severe conditions of the three units, is indicated in the following table:

POWER kVA						
OPERATION	**3 Units**	**Powerhouse**	**Water Intake**	**Spillway**	**Substation**	**Total**
CONTINUOUS TOTAL (kVA)	**460,5**	**151,5**	**5,0**	**5,0**	**5,0**	**627,0**
INTERMITTENT TOTAL (kVA)	**9,0**	**65,0**	**0**	**0**	**0**	**74,0**
SPORADIC TOTAL (kVA)	**4,5**	**167,5**	**30,0**	**22,5**	**15,0**	**239,5**

8.3 Maintenance

In the condition of maintenance of the plant will be considered the loads of 2 generating units operating and one stop, in maintenance.

8.3.1 Unit Loads

The highest load, in the maintenance condition of the plant, occurs with one generating unit stopped and the other two units in operation.

LOADS OF ONE UNIT									
CARGO DESCRIPTION	POWER								
	REAL	kVA							
		INSTALLED	START OF OPERATION	STARTING	OPERATION END	OPERATING	STOPPING	STOP'S END	STOPPED
Oil Pumps of Turbine's Speed Governor (2)	100 cv	200	100	100	100	100	100	100	
Oil Circulation Pumps of Generator's Thrust and Guide Bearing (2)	10 cv	20	10	10	10	10	10	10	
Oil Circulation Pumps of Turbine's Guide Bearing (2)	7,5 cv	15	7,5	7,5	7,5	7,5	7,5	7,5	
Oil Injection Pumps of Thrust Bearing (2)	15 cv	30	15	15			15	15	
Turbine Cover Draining Pumps (2)	3 cv	6	3	3	3	3	3	3	3
Generator Heating Resistors (1)	15 kW	15							15
Turbine Well Oil Steam Exhauster (1)	0,5 cv	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Pumps or Valve of Unit Cooling Water System (1)	1,5 cv	1,5	1,5					1,5	
Generator Excitation Cubicle (1)	10 kVA	10			10				
Auxiliaries of Step-Up Transformer (1)	30 kVA	30	30	30	30	30	30	30	
Cooling Water System Self-Cleaning Filter (1)	1,5 cv	1,5	1,5	1,5	1,5	1,5	1,5	1,5	
CONTINUOUS TOTAL (kVA)	-	-	**164,5**	**163,0**	**158,0**	**148,0**	**163,0**	**164,5**	**15,5**
INTERMITTENT TOTAL (kVA)	-	-	**3**	**3**	**3**	**3**	**3**	**3**	**3**
SPORADIC TOTAL (kVA)	-	-	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**	**0**
GRAND TOTAL (kVA)	-	**329,5**	**169,0**	**167,5**	**162,5**	**152,5**	**167,5**	**169,5**	**18,5**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

The loads of the three units are indicated in the following table:

OPERATING CONDITION OF THE UNITS		POWER kVA
Unit 1 Stop	**CONTINUOUS TOTAL**	**15,5**
	INTERMITTENT TOTAL	**3,0**
	SPORADIC TOTAL	**0**
Units 2 and 3 in Operation	**CONTINUOUS TOTAL**	**296,0**
	INTERMITTENT TOTAL	**6,0**
	SPORADIC TOTAL	**3,0**
Total of 3 Units	**CONTINUOUS TOTAL**	**311,5**
	INTERMITTENT TOTAL	**9,0**
	SPORADIC TOTAL	**3,0**

8.3.2 Powerhouse Loads

The Powerhouse Loads, in the maintenance condition, which considers the two generating units in operation and one in maintenance, are indicated below:

CARGO DESCRIPTION	POWER kVA
Drainage Pumps (2)	20
Air Compressors of Speed Governor (2)	30
Ventilation and Exhaust System (1 conj.)	75
Air Conditioning System (2)	30
Service Air Compressors (2)	15
Telecommunications System (2)	10
Battery Chargers (2)	5
Lighting and Heating Transformers (6)	30
People Lift (1)	7,5
Auxiliaries of the Diesel Emergency Generator Set (1)	1,5
Rotor Lifting System Pump (1)	3
Depletion Pumps of Draft Tube (2)	60
Fire Fighting Pumps (2)	50
Overhead Crane (1)	20
Power Outlets (10)	60
Mobile Insulating Oil Treatment System (1)	60
Mobile Lubricating Oil Treatment System (1)	30
Downstream Rolling Gantry (1)	15
CONTINUOUS TOTAL (kVA)	**151,5**
INTERMITTENT TOTAL (kVA)	**65,0**
SPORADIC TOTAL (kVA)	**305,5**
GRAND TOTAL (kVA)	**522,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

8.3.3 Water Inlet Loads

The loads of the water inlet in the maintenance condition, which considers two generating units in operation and one in maintenance, are indicated below:

CARGO DESCRIPTION	POWER kVA
Lighting and Heating Transformers (1)	5
Power Outlets (2)	15
Upstream Rolling Gantry (1)	20
Pumps of the Hydraulic Power Unit of the Water Intake Gates (2)	15
CONTINUOUS TOTAL (kVA)	**5,0**
INTERMITTENT TOTAL (kVA)	**0**
SPORADIC TOTAL (kVA)	**50,0**
GRAND TOTAL (kVA)	**55,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

8.3.4 Spillway Loads

The loads of the spillway, in the maintenance condition, which considers two generating units in operation and one in maintenance, are indicated below:

CARGO DESCRIPTION	POWER kVA
Lighting and Heating Transformers (1)	5
Power Outlets (2)	15
Spillway Rolling Gantry (1)	15
Hydraulic Power Unit of the Spillway Gates (2)	7,5
CONTINUOUS TOTAL (kVA)	**5,0**
INTERMITTENT TOTAL (kVA)	**0**
SPORADIC TOTAL (kVA)	**37,5**
GRAND TOTAL (kVA)	**42,5**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

8.3.5 HV Substation Loads

The loads of the HV substation, in the maintenance condition, which considers two generating units in operation and one in maintenance, are indicated below:

CARGO DESCRIPTION	POWER kVA
Lighting and Heating Transformers (1)	5
Power Outlets (2)	10
Motors of Switches and Circuit Breakers (1 Set)	5
CONTINUOUS TOTAL (kVA)	**5,0**
INTERMITTENT TOTAL (kVA)	**0**
SPORADIC TOTAL (kVA)	**15,0**
GRAND TOTAL (kVA)	**20,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

8.3.6 Summary

The summary of the loads of the plant, in the maintenance condition, which considers two generating units in operation and one in maintenance, is indicated in the following table:

POWER kVA						
OPERATION	**3 Units**	**Powerhouse**	**Powerhouse**	**Spillway**	**Substation**	**Total**
CONTINUOUS TOTAL (kVA)	**311,5**	**151,5**	**5,0**	**5,0**	**5,0**	**478,0**
INTERMITTENT TOTAL (kVA)	**9,0**	**65,0**	**0**	**0**	**0**	**74,0**
SPORADIC TOTAL (kVA)	**3,0**	**305,5**	**50,0**	**37,5**	**15,0**	**411,0**

8.4 Rated Power of Transformers

Based on the conditions of operation of the plant, normal and maintenance, analyzed above, the loads considered are indicated below:

POWER kVA		
OPERATION	Normal	Maintenance
CONTINUOUS TOTAL (kVA)	627,0	478,0
INTERMITTENT TOTAL (kVA)	74,0	74,0
SPORADIC TOTAL (kVA)	239,5	411,0
GRAND TOTAL	940,5	963,0

According to the data obtained, the power of the transformer to meet the highest continuous load of the plant, which occurs during normal operation, should be 627.0 kVA, since the continuous load during the maintenance operation is 478.0 kVA.

If in addition to the continuous load of 627.0 kVA, during the normal operation of the plant, we consider the operation of the mobile insulating oil treatment system (60kVA) and the drainage pump (20kVA) or the governor air compressor (30kVA), totaling an additional load of 80 or 90kVA, the minimum rated power of the transformer should be 707.0 kVA or 717,0 kVA.

If in addition to the continuous load of 478.0 kVA, during the maintenance operation of the plant, we consider the operation of the mobile insulating oil treatment system (60kVA), the drainage pump (20kVA), the regulating air compressor (30kVA) and the depletion pumps (2x30kVA), totaling an additional load of 170kVA, the minimum power of the transformer should be 648.0.0 kVA.

To meet both situations, the minimum rated power of the transformers should be 717.0 kVA. To meet these loads, the standardized nominal powers of transformers, available in the market, are 750 and 1000KVA. To meet the design safety factors and uncertainty of the initial design information, the rated power of the plant's auxiliary service transformers must be 1000 kVA.

The transformers installed inside the powerhouse are of the dry type, whose short circuit impedance is usually 6%. The impedance of oil transformers is usually 5%. The value of the short circuit impedance, as well as the derivations of the primary winding, shall be defined in the corresponding specification, depending on the data of the loads and study of the voltage variations at the various points of the system.

8.5 Voltages in the Transformer's Secondary

To make a quick check of the voltage values in the secondary of the transformers, we will consider the information in the technical information IT.EL.SA.CA.01.R1 Rated Voltage and Voltage Variations, where it is defined that the voltage in the primary may vary in the range of 93 to 105% of the rated voltage.

Using the spreadsheet PL.EL.SA.AC.01.R1 POWER TRANSFORMERS - Voltage Calculation in the Terminals, and considering the primary voltage in the transformer at the rated value, use of the nominal derivation, maximum constant power load of 617kVA (≅717kVA-100hp), 460V, power factor 0.85, which after starting the engine of 100hp, will total the estimated 717kVA, and the start of a motor with the following data:

Rated Power:100hp.

Rated voltage: 460V.

Starting current: 1054A

Power factor at start: 0.3

In the above conditions the voltage in the secondary of the transformer will be 442.87V.

SYSTEM DATA			
Transformer	VP_n	Rated Primary Voltage of Transformer (kV)	13,8
	VS_n	Rated Secondary Voltage of Transformer (V)	480
	PTF_n	Rated Power of Transformer (kVA)	1000
	Z_n	Rated Impedance of Transformer (%)	6
	R_n	Rated Resistence of Transformer (%)	1
	VP	Primary Voltage on Transformer (kV)	13,8
	k	Tap Voltage Used of Transformer (pu)	1
Loads Data	Pc_{Kn}	Rated Power of Constant Load (kVA)	617
	Vc_{Kn}	Rated Voltage of Constant Load (V)	460
	FPc_K	Power Factor of Constant Load	0,85
	Pc_{Vn}	Rated Power of Variable Load (kVA)	
	Vc_{Vn}	Rated Voltage of Variable Load (V)	
	FPc_V	Power Factor of Variable Load	
	VM_{pn}	Rated Voltage of Motor(s) (V)	460
	IM_{pn}	Starting Current of Motor(s) at Rated Voltage (A)	1054
	FPM_p	Power factor of Motor(s) at Starting	0,3

VT_s	*Voltage on Secondary Terminals of Transformer (V)*	442,87

Making some simulations, changing the value of the voltage in the primary of the transformer (13.8KV, -7%, +5%), the derivation used (0.95-1.0-1.05), the constant load power 900kVA (≅1000kVA-100hp) and 617kVA (≅717kVA-100hp), considering the start of the 100hp engine as the last load to be applied, we can prepare the following table:

VP (kV)	k	Pc_{Kn} (kVA)	VT_S (V)
12,834	0,95	900	430,20
	1		403,32
	1,05		377,41
	0,95	617	436,55
	1		406,97
	1,05		385,38
13,8	0,95	900	466,03
	1		436,80
	1,05		409,57
	0,95	617	416,80
	1		442,87
	1,05		416,80
14,49	0,95	900	490,93
	1		460,55
	1,05		432,34
	0,95	617	495,73
	1		466,27
	1,05		439,13

Other simulations can be explored by the user to define their application to the specific conditions of their installation and operating conditions.

9 EMERGENCY GENERATOR DIESEL SET

The power of the plant's emergency generator diesel set must meet, in the permanent and transient conditions of emergency operation, the consumption of the continuous loads and, simultaneously, the consumption of the operation of intermittent and sporadic loads of the installation.

9.1 Data Analysis

To define the power of the plant's emergency generator diesel set it is necessary to analyze and interpret the data from the tables and the operating conditions.

9.1.1 Units Loads

The emergency operating condition of the plant occurs when the plant's alternating current sources fail, causing the generating units to stop. The shutdown of the units must occur, exceptionally, without the need for the operation of their auxiliary systems. The emergency diesel generator set must automatically depart and feed the essential loads of the plant and, to restore the normal operating condition of the plant, must feed the auxiliary systems of the first unit during its start-up. Before restoring normal system condition, non-essential loads can be fed if the emergency diesel generator set has the capacity to do so.

CARGO DESCRIPTION	POWER kVA					
	START OF OPERATION	STARTING	OPERATION END	OPERATING	STOPPING	STOP'S END
Oil Pumps of Turbine's Speed Governor (2)	100	100	100	100	100	100
Oil Circulation Pumps of Generator's Thrust and Guide Bearing (2)	10	10	10	10	10	10
Oil Circulation Pumps of Turbine's Guide Bearing (2)	7,5	7,5	7,5	7,5	7,5	7,5
Oil Injection Pumps of Thrust Bearing (2)	15	15			15	15
Turbine Cover Draining Pumps (2)	3	3	3	3	3	3
Generator Heating Resistors (1)						
Turbine Well Oil Steam Exhauster (1)	0,5	0,5	0,5	0,5	0,5	0,5
Pumps or Valve of Unit Cooling Water System (1)	1,5					1,5
Generator Excitation Cubicle (1)			10			
Auxiliaries of Step-Up Transformer (1)	30	30	30	30	30	30
Cooling Water System Self-Cleaning Filter (1)	1,5	1,5	1,5	1,5	1,5	1,5
CONTINUOUS TOTAL (kVA)	**164,5**	**163,0**	**158,0**	**148,0**	**163,0**	**164,5**
INTERMITTENT TOTAL (kVA)	**3**	**3**	**3**	**3**	**3**	**3**
SPORADIC TOTAL (kVA)	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**	**1,5**
GRAND TOTAL (kVA)	**169,0**	**167,5**	**162,5**	**152,5**	**167,5**	**169,5**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

9.1.2 Powerhouse Loads

The Powerhouse Loads, in emergency operating conditions, are indicated below:

CARGO DESCRIPTION	POWER kVA
Drainage Pumps (2)	20
Air Compressors of Speed Governor (2)	30
Ventilation and Exhaust System (1 conj.)	10
Air Conditioning System (2)	15
Service Air Compressors (2)	15
Telecommunications System (2)	10
Battery Chargers (2)	5
Lighting and Heating Transformers (6)	30
People Lift (1)	7,5
Auxiliaries of the Diesel Emergency Generator Set (1)	1,5
Fire Fighting Pumps (2)	50
CONTINUOUS TOTAL (kVA)	**71,5**
INTERMITTENT TOTAL (kVA)	**65,0**
SPORADIC TOTAL (kVA)	**57,5**
GRAND TOTAL (kVA)	**194,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

9.1.3 Water Intake Loads

The loads of the water intake, in emergency operating conditions, are indicated below:

CARGO DESCRIPTION	POWER kVA
Lighting and Heating Transformers (1)	5
Pumps of the Hydraulic Power Unit of the Water Intake Gates (2)	15
CONTINUOUS TOTAL (kVA)	**5,0**
INTERMITTENT TOTAL (kVA)	**0**
SPORADIC TOTAL (kVA)	**15,0**
GRAND TOTAL (kVA)	**20,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

9.1.4 Spillway Loads

The loads of the spillway, under the conditions of operation in emergency, are indicated below:

CARGO DESCRIPTION	POWER kVA
Lighting and Heating Transformers (1)	5
Hydraulic Power Unit of the Spillway Gates (2)	7,5
CONTINUOUS TOTAL (kVA)	**5,0**
INTERMITTENT TOTAL (kVA)	**0**
SPORADIC TOTAL (kVA)	**7,5**
GRAND TOTAL (kVA)	**12,5**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

9.1.5 HV Substation Loads

The loads of the HV substation, under emergency operating conditions, are indicated below:

CARGO DESCRIPTION	POWER kVA
Lighting and Heating Transformers (1)	5
Motors of Switches and Circuit Breakers (1 Set)	5
CONTINUOUS TOTAL (kVA)	**5,0**
INTERMITTENT TOTAL (kVA)	**0**
SPORADIC TOTAL (kVA)	**5,0**
GRAND TOTAL (kVA)	**10,0**

NOTE: The numbers in parentheses next to the cargo description indicate the quantity.

9.1.6 Summary

The summary of the loads of the plant, in the condition of operation in emergency, is indicated in the following table:

POWER kVA						
OPERATION	**1st Unit**	**Powerhouse**	**Water Intake**	**Spillway**	**Substation**	**Total**
CONTINUOUS TOTAL (kVA)	**164,5**	**71,5**	**5,0**	**5,0**	**5,0**	**251,0**
INTERMITTENT TOTAL (kVA)	**3**	**65,0**	**0**	**0**	**0**	**68,0**
SPORADIC TOTAL (kVA)	**1,5**	**57,5**	**15,0**	**7,5**	**5,0**	**86,5**

9.2 Rated Power of the Emergency Generator Diesel Set

Based on the operating condition of the plant in emergency, analyzed above, the loads considered are indicated below:

POWER kVA	
OPERATION	**Emergency**
CONTINUOUS TOTAL (kVA)	**251,0**
INTERMITTENT TOTAL (kVA)	**68,0**
SPORADIC TOTAL (kVA)	**86,5**
GRAND TOTAL	**405,5**

According to the data obtained, the power of the emergency diesel generator set to meet the highest continuous load of the plant, which occurs during emergency operation, should be 251.0 kVA.

If in addition to the continuous load of 251.0 kVA, during the emergency operation of the plant, we consider as continuous the operation of the drainage pump (20kVA) and the governor air compressor (30kVA), totaling an additional load of 50kVA, the minimum continuous rated power of the emergency generator diesel set should be 301.0 kVA.

Adopting a factor of 20% to meet the variation of estimated powers and future additions, the continuous power (prime) of the emergency generator diesel group should be 360kVA.

The sets are specified for operation with continuous apparent power (prime) and power factor 0.8. This power is the power supplied at the alternator terminals, i.e., for a group with a prime rated power of 360kVA, the alternator provides a continuous active power (prime) of 288kW and, in emergency (stand by), an apparent power of 396kVA and an active power of 316.8kW. However, the choice of an emergency diesel generator set is not such a simple task, since the transient operating conditions of the loads and the voltage variations in the system must be considered.

Diesel sets are supplied for various purposes such as continuous operation and emergency. Groups for continuous operation should be specified to operate at low rotation (typically 1200 rpm) and emergency groups at high rpm (typically 1800 rpm). The rated power of the same diesel engine is higher when it operates at 1800 rpm (60Hz) instead of 1500 rpm (50Hz). The values of these powers are reported by the manufacturers and are usually directly proportional to the rotation.

Emergency diesel generator sets can operate with an overload of 10% above the rated power (continuous or prime), for 1 hour every 12 hours of operation. This power is called the standby power.

In the definition of diesel generator sets the use of hybrid groups should be considered when the rated power of the diesel engine does not correspond to the rated power of the alternator.

9.3 Alternator

The alternator is sized to meet the active and apparent powers and, its voltage governor, must maintain voltage of the terminals at the adjusted value.

The power of the emergency diesel generator set will depend on the operating conditions and characteristics of the loads, the permissible voltage variations of the installation components and the characteristics of the diesel generator sets available on the market. There is no standard formula to consider. What must be done is to calculate the consumptions, permanent and transient of the loads, and consider the worst condition.

9.3.1 Alternator Operating Voltage

The alternator voltage of the set is kept constant at the adjusted operating voltage value. Thus, the value of the operating voltage of an alternator, with a nominal voltage of 480V, can be adjusted to a higher value, for example, 506V (460V +10%), which meets the voltage limits of the 460V and 480V equipment. This adjustment allows that, during the transient periods of operation (starting of motors and application of loads), the voltage in the loads remains within acceptable minimum limits and, in the periods of normal operation, does not exceed the maximum limits bearable by the components.

The operating voltage of the alternator, adjusted at 506V, will imply that the maximum voltage in the secondary of the transformers of 480-120V (4:1 ratio) will be 126.5V (115V+10%), that is, within the maximum limit of permissible voltage for relay coils and contactors of rated voltage 115V.

9.3.2 Voltage Variations

The voltage variations normally allowed in the equipment are 480V±10% (432V to 528V) for the loads in general; 460V, -5%, +10% (437V to 506V) for motors during normal operation and, considering the start of the motors is direct to full voltage, 460V-10% (414V), during starting.

When the motors controls are powered by direct current, there is no concern about voltage drop in the motors during starting.

As the minimum voltage in the coils of the contactors of the motors should be, as a rule, 85% of the nominal voltage, this minimum value will be 97.75V for contactors of 115V. If the motor controls are powered by 480-120V (4:1) ratio control transformers, and these controls are close to the motors (most unfavorable case), for the 414V voltage in the motors, the voltage in the control will be 103.5V, that is, 90% of the nominal voltage of contactors with nominal 115V coils.

The minimum voltage in the terminals of the motors, during start-up, could be admitted at 391V (460V, -15%), especially in the case of motors that drive pumps and compressors, which are the majority of the loads of a plant. Note that there are contactor manufacturers that ensure that contactors remain closed with voltages up to less than 70% of the nominal voltage.

Vital plant loads such as battery chargers, communication systems, and digital supervision and control systems (SDSC) can operate with voltage drops of 15%, i.e., 408V (480V-15%). However, these and other loads such as heating, cargo handling and lighting systems, in case of voltage drops of more than 15% do not suffer discontinuity in their operation, because as soon as the transient problem disappears, they return to normal operation. Therefore, exceptionally, this condition of emergency operation can be admitted.

For the above, the operating voltage of the alternator can be adjusted to 506V, and the minimum transient voltage allowed can be 414V and can reach up to 391V.

9.3.3 Transient Reactance X'd

The transient reactance of the alternator is defined according to the maximum permissible voltage drop at its terminals during the transitional periods of operation of the emergency diesel set, mainly during the starting of motors and/or application of a set of loads.

To reduce the drop of voltage in the alternator during the transitory periods, the transient reactance of the alternator should be calculated to limit its values.

As the power defined for the alternator of the emergency diesel set is 360kVA, the worst transient condition will be when the last load to start will be the motor of oil pumps of turbine's speed governor (100hp≈100kVA), that is, when the group is feeding an initial load of 260kVA (360kVA-100kVA).

The voltage at the terminals of the alternator depends on the voltage considered at the terminals of the motors and the voltage drop in the supply circuit. However, we can guarantee that the voltage at the alternator terminals will be higher than the voltage at the motor terminals due to the voltage drop. Therefore, as the starting current of the motors is proportional to the value of the voltage, for the purpose of calculating the transient reactance of the alternator, we can consider the voltage admitted at the terminals of the motor as being the voltage at the terminals of the alternator.

9.3.3.1 Considered Loads

For the calculation of the transient reactance of the alternator, the following estimated loads shall be considered:

a) Constant Power Initial Load

Rated Power: 210kVA.

Rated Voltage: 460V.

Power Factor: 0.85.

b) Variable Power Initial Load

Rated Power: 50kVA.

Rated Voltage: 480V.

Power Factor: 0.9

c) Motor Starting

Rated Power:100hp.

Rated voltage: 460V.

Starting current: 1054A

Power factor at start: 0.3

9.3.3.2 Calculation of Transient Reactance

Using the worksheet PL.EL.SA.CA.02.R1 DIESEL GENERATORS SETS - Calculations of Transient Reactance, the transient reactance of the alternator will be calculated considering the informed loads, nominal voltage of the alternator 480V, adjusted value of the voltage in 506V, nominal power of 360kVA.

For Voltage in Alternator Terminals: 391V

DATA SYSTEM				
Alternator		VG_n	Rated Voltage of Alternator (V)	480
		VG_A	Adjusted Voltage of Operating the Alternator (V)	506
		PG_n	Rated Power of Alternator (kVA)	360
		VG_T	Voltage at Alternator Terminals (V)	391
Loads Data	Initial	Pc_{kn}	Rated Power of Initial Constant Load (kVA)	210
		Vc_{kn}	Rated Voltage of Initial Constant Load (V)	460
		FPc_k	Power Factor of Initial Constant Load	0,85
		Pc_{vn}	Rated Power of Initial Variable Load (kVA)	50
		Vc_{vn}	Rated Voltage of Initial Variable Load (V)	480
		FPc_v	Power Factor of Initial Variable Load	0,9
	Load to be Applied	PC_{Kn}	Rated Power of Constant Load (kVA)	
		VC_{Kn}	Rated Voltage of Constant Load (V)	
		FPC_K	Power Factor of Constant Load	
		PC_{Vn}	Rated Power of Variable Load (kVA)	
		VC_{Vn}	Rated Voltage of Variable Load (V)	
		FPC_V	Power Factor of Variable Load	
		VM_{Pn}	Rated Voltage of Motor(s) (V)	460
		IM_{Pn}	Starting Current of Motor(s) at Rated Voltage (A)	1054
		FPM_P	Power Factor of Motor(s) at Starting	0,3

Transient Reactance of Alternator	$X'G_n$ (%)	**11,31**

For Alternator Terminals Voltage: 414V.

DATA SYSTEM				
Alternator		VG_n	Rated Voltage of Alternator (V)	480
Alternator		VG_A	Adjusted Voltage of Operating the Alternator (V)	506
Alternator		PG_n	Rated Power of Alternator (kVA)	360
Alternator		VG_T	Voltage at Alternator Terminals (V)	414
Loads Data	Initial	Pc_{kn}	Rated Power of Initial Constant Load (kVA)	210
Loads Data	Initial	Vc_{kn}	Rated Voltage of Initial Constant Load (V)	460
Loads Data	Initial	FPc_k	Power Factor of Initial Constant Load	0,85
Loads Data	Initial	Pc_{vn}	Rated Power of Initial Variable Load (kVA)	50
Loads Data	Initial	Vc_{vn}	Rated Voltage of Initial Variable Load (V)	480
Loads Data	Initial	FPc_v	Power Factor of Initial Variable Load	0,9
Loads Data	Load to be Applied	PC_{Kn}	Rated Power of Constant Load (kVA)	
Loads Data	Load to be Applied	VC_{Kn}	Rated Voltage of Constant Load (V)	
Loads Data	Load to be Applied	FPC_K	Power Factor of Constant Load	
Loads Data	Load to be Applied	PC_{Vn}	Rated Power of Variable Load (kVA)	
Loads Data	Load to be Applied	VC_{Vn}	Rated Voltage of Variable Load (V)	
Loads Data	Load to be Applied	FPC_V	Power Factor of Variable Load	
Loads Data	Load to be Applied	VM_{Pn}	Rated Voltage of Motor(s) (V)	460
Loads Data	Load to be Applied	IM_{Pn}	Starting Current of Motor(s) at Rated Voltage (A)	1054
Loads Data	Load to be Applied	FPM_P	Power Factor of Motor(s) at Starting	0,3

Transient Reactance of Alternator	$X'G_n$ (%)	**8,71**

We then have the maximum reactance of 11.31% and 8.71% in case we consider the minimum voltages in the 391V and 414V motors, respectively.

9.3.4 Choice of Alternator

The rated power of the alternator is defined as a function of the active and apparent powers requested by the loads during the permanent and transient operating regimes, the value of the rated alternator voltage, its operating voltage, the transient reactance of the alternator, and the permissible variations of the voltages in the loads and in the system.

It turns out that there is no generator with power of 360kVA and reactance of 11.31% and 8.71%. Therefore, we will have to choose, within the alternators available on the market, an alternator that is equivalent to the defined.

Based on the information of alternators of the WEG catalog, we verify that there are two alternators that meet the values calculated above, are the models 280MI30AI and 280MI40A, whose data are indicated below:

	Modelo	480 V - Y / 240 V - YY					
		ΔT	80 °C	105 °C	125 °C	150 °C	163 °C
Linha AG10 - AG10	280MI30AI	kVA	456	510	**570**	600	650
		kW	365	408	**456**	480	520
	280MI40AI	kVA	484	565	**605**	650	691
		kW	387	452	**484**	520	553
	315MI10AI	kVA	520	596	**650**	700	750
		kW	416	477	**520**	560	600
	315MI15AI	kVA	570	650	**710**	780	825
		kW	456	520	**568**	624	660
	315MI20AI	kVA	642	736	**803**	875	906
		kW	514	589	**642**	700	725
	315MI30AI	kVA	740	850	**925**	1010	1056
		kW	592	680	**740**	808	845

	Modelo	Xd' (%) Saturada
		220/440 V
nha AG10 - AG10	250SI10AI	17,43
	250SI20AI	18,39
	250MI00AI	18,40
	250MI10AI	16,58
	250MI20AI	16,40
	280MI20AI	16,53
	280MI30AI	19,70
	280MI40AI	13,80

As the transient reactance are referred to the voltage of 440V, the values referred to the voltage of 480V and power 360kVA, we have:

For the 280MI30AI (570kVA)

$$Z_{G(480)} = 19{,}7\frac{440^2}{480^2}\frac{360}{570} = 10{,}45\%$$

For the 280MI40AI (605kVA)

$$Z_{G(480)} = 13{,}8\frac{440^2}{480^2}\frac{360}{605} = 6{,}90\%$$

The alternator model 280MI30AI (570kVA) meets only the condition of the minimum voltage of 391V and the 280MI40AI (605kVA) meets both conditions (391V and 414V).

Another way to check if this equivalence will be met is to analyze the condition:

$$\frac{P_{Gn}}{X'_{Gn}} \geq \frac{P_{Gc}}{X'_{Gc}}$$

Where:

P_{Gn} Equivalent Alternator Rated Power (kVA)

P_{Gc} Alternator's Calculated Rated Power (kVA)

X'_{Gn} Equivalent Alternator Transient Reactance (%)

X'_{Gc} Alternator's Calculated Transient Reactance (%)

Considering the minimum voltage of 391V at the alternator terminals,

$$\frac{P_{Gn}}{X'_{Gn}} \geq \frac{360}{11{,}31} = 31{,}83$$

Considering the minimum voltage of 414V at the alternator terminals,

$$\frac{P_{Gn}}{X'_{Gn}} \geq \frac{360}{8{,}71} = 41{,}33$$

As the transient reactance are referred to at the voltage of 440V, the values referred to at the voltage of 480V shall be:

$$Z_{G(480)} = Z_{G(440)}\frac{440^2}{480^2}$$

For the alternator 280MI30AI, whose transient reactance, in 440V and 570kVA is 19.7%.

$$Z_{G(480)} = 19{,}7\frac{440^2}{480^2} = 16{,}55\%$$

$$\frac{P_{Gn}}{X'_{Gn}} = \frac{570}{16{,}55} = 34{,}44 \geq 31{,}83$$

For the alternator 280MI40AI, whose transient reactance, in 440V and 605kVA is 13.8%.

$$Z_{G(480)} = 13{,}8\frac{440^2}{480^2} = 11{,}60\%$$

$$\frac{P_{Gn}}{X'_{Gn}} = \frac{605}{11{,}6} = 52{,}16 \geq 31{,}83 \text{ e } 41{,}33$$

The alternator model 280MI30AI (570kVA) meets only the condition of the minimum voltage of 391V and the 280MI40AI (605kVA) meets both conditions (391V and 414V).

9.3.5 Calculation of Minimum Voltages

Using the spreadsheet PL.EL.SA.CA.03.R1 DIESEL GENERATOR SETS - Voltage Calculation in the Terminals, for the model 280MI40AI (605kVA), considering the data referred to the power 360kVA, 480V, 6.90%, the minimum voltage will be 431.03V:

DADOS DO SISTEMA				
Alternador		VG_n	Tensão Nominal do Alternador (V)	480
		VG_A	Tensão de Operação Ajustada do Alternador(V)	506
		PG_n	Potência Nominal do Alternador (kVA)	360
		$Z'G_n$	Reatância Transitória Nominal do Alternador (%)	6,90
Dados das Cargas	Inicial	Pc_{kn}	Potência Nominal da Carga Inicial Constante (kVA)	210
		Vc_{kn}	Tensão Nominal da Carga Inicial Constante (V)	460
		FPc_k	Fator de Potência da Carga Inicial Constante	0,85
		Pc_{vn}	Potência Nominal da Carga Inicial Variável (kVA)	50
		Vc_{vn}	Tensão Nominal da Carga Inicial Variável (V)	480
		FPc_v	Fator de Potência da Carga Inicial Variável	0,9
	Carga a ser Aplicadda	PC_{Kn}	Potência Nominal da Carga Constante (kVA)	
		VC_{Kn}	Tensão Nominal da Carga Constante (V)	
		FPC_K	Fator de Potência da Carga Constante	
		PC_{Vn}	Potência Nominal da Carga Variável (kVA)	
		VC_{Vn}	Tensão Nominal da Carga Variável (V)	
		FPC_V	Fator de Potência da Carga Variável	
		VM_{Pn}	Tensão Nominal do(s) Motor(es) (V)	460
		IM_{Pn}	Corrente de Partida do(s) Motor(es) na Tensão Nominal (A)	1054
		FPM_P	Fator de Potência do(s) Motor(es) na Partida	0,3

Tensão nos Terminais do Alternador (V)	V_{GT} *(%)*	**431,03**

The following calculations for power 605kVA, 440V, 13.80% and power 605kVA, 480V, 11.60%. The results are the same, because the voltage differences found in the second decimal place are due to the rounding of the values entered in the worksheet.

DADOS DO SISTEMA				
Alternador		VG_n	Tensão Nominal do Alternador (V)	440
		VG_A	Tensão de Operação Ajustada do Alternador(V)	506
		PG_n	Potência Nominal do Alternador (kVA)	605
		$Z'G_n$	Reatância Transitória Nominal do Alternador (%)	13,80
Dados das Cargas	Inicial	Pc_{kn}	Potência Nominal da Carga Inicial Constante (kVA)	210
		Vc_{kn}	Tensão Nominal da Carga Inicial Constante (V)	460
		FPc_k	Fator de Potência da Carga Inicial Constante	0,85
		Pc_{vn}	Potência Nominal da Carga Inicial Variável (kVA)	50
		Vc_{vn}	Tensão Nominal da Carga Inicial Variável (V)	480
		FPc_v	Fator de Potência da Carga Inicial Variável	0,9
	Carga a ser Aplicadda	PC_{Kn}	Potência Nominal da Carga Constante (kVA)	
		VC_{Kn}	Tensão Nominal da Carga Constante (V)	
		FPC_K	Fator de Potência da Carga Constante	
		PC_{Vn}	Potência Nominal da Carga Variável (kVA)	
		VC_{Vn}	Tensão Nominal da Carga Variável (V)	
		FPC_V	Fator de Potência da Carga Variável	
		VM_{Pn}	Tensão Nominal do(s) Motor(es) (V)	460
		IM_{Pn}	Corrente de Partida do(s) Motor(es) na Tensão Nominal (A)	1054
		FPM_P	Fator de Potência do(s) Motor(es) na Partida	0,3

Tensão nos Terminais do Alternador (V)	V_{GT} *(%)*	**431,03**

DADOS DO SISTEMA			
Alternador	VG_n	Tensão Nominal do Alternador (V)	480
	VG_A	Tensão de Operação Ajustada do Alternador(V)	506
	PG_n	Potência Nominal do Alternador (kVA)	605
	$Z'G_n$	Reatância Transitória Nominal do Alternador (%)	11,60
Dados das Cargas – Inicial	Pc_{kn}	Potência Nominal da Carga Inicial Constante (kVA)	210
	Vc_{kn}	Tensão Nominal da Carga Inicial Constante (V)	460
	FPc_k	Fator de Potência da Carga Inicial Constante	0,85
	Pc_{vn}	Potência Nominal da Carga Inicial Variável (kVA)	50
	Vc_{vn}	Tensão Nominal da Carga Inicial Variável (V)	480
	FPc_v	Fator de Potência da Carga Inicial Variável	0,9
Dados das Cargas – Carga a ser Aplicadda	PC_{Kn}	Potência Nominal da Carga Constante (kVA)	
	VC_{Kn}	Tensão Nominal da Carga Constante (V)	
	FPC_K	Fator de Potência da Carga Constante	
	PC_{Vn}	Potência Nominal da Carga Variável (kVA)	
	VC_{Vn}	Tensão Nominal da Carga Variável (V)	
	FPC_V	Fator de Potência da Carga Variável	
	VM_{Pn}	Tensão Nominal do(s) Motor(es) (V)	460
	IM_{Pn}	Corrente de Partida do(s) Motor(es) na Tensão Nominal (A)	1054
	FPM_P	Fator de Potência do(s) Motor(es) na Partida	0,3

Tensão nos Terminais do Alternador (V)	V_{GT} *(%)*	**431,00**

For the model 280MI30AI (570kVA), 440V, 19.70%, the minimum voltage will be 398.40V. The voltages will not be calculated for other values of power, voltage and reactance because, as we have seen, the voltages will be equal.

DADOS DO SISTEMA			
Alternador	VG_n	Tensão Nominal do Alternador (V)	440
	VG_A	Tensão de Operação Ajustada do Alternador(V)	506
	PG_n	Potência Nominal do Alternador (kVA)	570
	$Z'G_n$	Reatância Transitória Nominal do Alternador (%)	19,70
Dados das Cargas – Inicial	Pc_{kn}	Potência Nominal da Carga Inicial Constante (kVA)	210
	Vc_{kn}	Tensão Nominal da Carga Inicial Constante (V)	460
	FPc_k	Fator de Potência da Carga Inicial Constante	0,85
	Pc_{vn}	Potência Nominal da Carga Inicial Variável (kVA)	50
	Vc_{vn}	Tensão Nominal da Carga Inicial Variável (V)	480
	FPc_v	Fator de Potência da Carga Inicial Variável	0,9
Dados das Cargas – Carga a ser Aplicadda	PC_{Kn}	Potência Nominal da Carga Constante (kVA)	
	VC_{Kn}	Tensão Nominal da Carga Constante (V)	
	FPC_K	Fator de Potência da Carga Constante	
	PC_{Vn}	Potência Nominal da Carga Variável (kVA)	
	VC_{Vn}	Tensão Nominal da Carga Variável (V)	
	FPC_V	Fator de Potência da Carga Variável	
	VM_{Pn}	Tensão Nominal do(s) Motor(es) (V)	460
	IM_{Pn}	Corrente de Partida do(s) Motor(es) na Tensão Nominal (A)	1054
	FPM_P	Fator de Potência do(s) Motor(es) na Partida	0,3

Tensão nos Terminais do Alternador (V)	V_{GT} *(%)*	**398,40**

9.3.6 Definition of the Alternator

In the analysis of the data and calculations made, it is verified that the alternator model 280MI40AI, of 605kVA, with 35kVA more power than the model 280MI30AI, has a minimum voltage much higher, which justifies its choice. Therefore, with the results found it can be defined that the alternator model will be the 280MI40AI with continuous rated power of 605kVA.

9.4 Diesel Engine

The diesel engine must be sized to drive the assembly and provide the active power required by the alternator, and its speed regulator must maintain the rotation of the assembly at the set value. The diesel engine data must be agreed with the manufacturer of the assembly, so that the diesel engine activates the alternator at the defined load conditions, also considering the conditions of the installation site and other requirements defined by the Customer, such as overload factor and others. Therefore, data on loads, requirements and operating conditions must be provided to the group supplier.

9.4.1 Calculation of the Requested Active Power

The diesel engine must be able to drive the alternator in any condition of operation of the loads. Therefore, it must be able to meet, at a minimum, the active power requested by the load to the alternator.

$$P_{requested\ to\ alternator}(kW) = P_{initial\ load}(kW) + P_{starting\ motor\ 100hp}(kW)$$

To estimating the power of the diesel engine, as the worst condition considered was with the initial load of 260kVA and motor starting of 100hp, the active power requested by the loads to the alternator, using the criterion of approximation 1cv=1hp=1kW=1kVA, will be:

Como a pior condição considerada foi com a carga inicial de 260kVA e partida do motor de 100hp, a potência ativa solicitada pelas cargas ao alternador será:

$$P_{cinitial\ load}(kW) = 260kVA = 260kW$$

Considering the motor's rated data:

$$P_{starting\ motor\ 100h}\ (kW) = P(kW) = \sqrt{3}x0{,}46x1054x0{,}3 = 252kW$$

$$P_{requested\ to\ alternator}(kW) = 260 + 252 = 512kW$$

The power requested by the alternator to the diesel engine will depend on its performance for the requested power.

Assuming that the yield for this requested power is 90%, the power requested from the diesel engine will be:

$$P_{engine\ diesel\ minimum}(kW) = \frac{512}{0{,}9} = 569kW$$

9.5 Conclusion

The emergency generator diesel set may be a hybrid set, because although the alternator has a continuous power (prime) of 605kVA (484kW), which would imply a standby power of 665kVA (532kW), the diesel engine should not necessarily meet these powers. Therefore, to define the components of the group, the operating conditions and data of the loads must be clearly informed to the supplier, who will define the best composition that technically and commercially meets the needs of the installation.

9.5.1 Group Rated Power

The data of the emergency diesel generator set may be:

Continuous Power (Prime): 360kVA

Emergency Power (Stand By): 396kVA

Power Factor: 0.8

Rated voltage: 480V.

Rated frequency: 60Hz.

9.5.2 Alternator

Manufacturer: WEG

Model: 280MI40AI

Rated Power: 605kVA.

Rated voltage: 480V.

Rated frequency: 60Hz.

Operating Voltage: 506V

Transient Reactance in 480V: 11.60%

Note: Another alternator model can be defined by the group supplier but must meet the equivalence to meet the installation.

9.5.3 Diesel Engine

The minimum net power provided by the diesel engine the alternator shall be 569kW. Depending on the application of the motor and considering that the frequency of the system is 60Hz, the nominal rotation should be 1800rpm.

9.6 Use of the Set

The set can be supplied with a name plate with the rated data specified for the set, but the alternator and engine data name plates must be those provided to allow the user, depending on their eventual needs, to use the group within the limitations of the equipment. Although the set has been sized with a rated power of 360kVA, the user can use the group in other operating conditions, different from those expected, but within the capabilities of the components of the supplied group and limitations of the installation.