# APPLICATIONS

**ÍNDEX** **PÁG.**

## 1 - PURPOSE

The purpose of this document is to present examples of applications of the spreadsheets, based on the technical and theoretical information listed in the reference documents.

## 2 - REFERENCE DOCUMENTS

### 2.1 - Technical Information

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

IT.EL.SA.CA.02 Power Transformer and Emergency Diesel Generator Set - Sizing

IT.EL.SA.CA.03 Short Circuit - Calculations of Currents

IT.EL.SA.CC.01 Direct Current Systems

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

TE.EL.SA.CA.02 DIESEL GENERATORS SETS - Calculation of Transient Reactance and Terminals Voltage

TE.EL.SA.CA.03 Hydroelectric Power Plant - Generation Voltage Calculation

TE.EL.SA.CA.04 Feeders - Voltage Calculation on the Load and Source

TE.EL.SA.CA.05 Feeders - Criteria for Sizing

### 2.2 - Spreadsheets

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

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

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

PL.EL.SA.CA.04 Feeders - Load Voltage Calculation

PL.EL.SA.CA.05 Feeders - Source Voltage Calculation

PL.EL.SA.CA.06 Hydroelectric Power Plant - Generation Voltage Calculation

PL.SA.EL.CA.06 Feeders - Criteria for Sizing

### 2.3 - Publications

IEEE Transactions on Industry Applications, Vol. IA-10 March/April 1974 - Short Circuit ABC - Learn It in an Hour (Moon H. Yuen)

## 3 - INITIAL CONSIDERATIONS

This technical information is not intended to cover all the possibilities, but to allow the user to, based on the examples of these applications, solve the problems that involve their needs, exploring alternatives and/or deepening the ones presented. Therefore, it is not intended, in this informative, to define a general criterion to define the system of auxiliary services.

As this technical information is not the complete calculation memory of a project, the calculations were not made to define all the feeders, but the necessary tools were used, and the main concepts were applied.

For systems and equipment, the information defined are only the necessary to solve the examples of the applications considered.

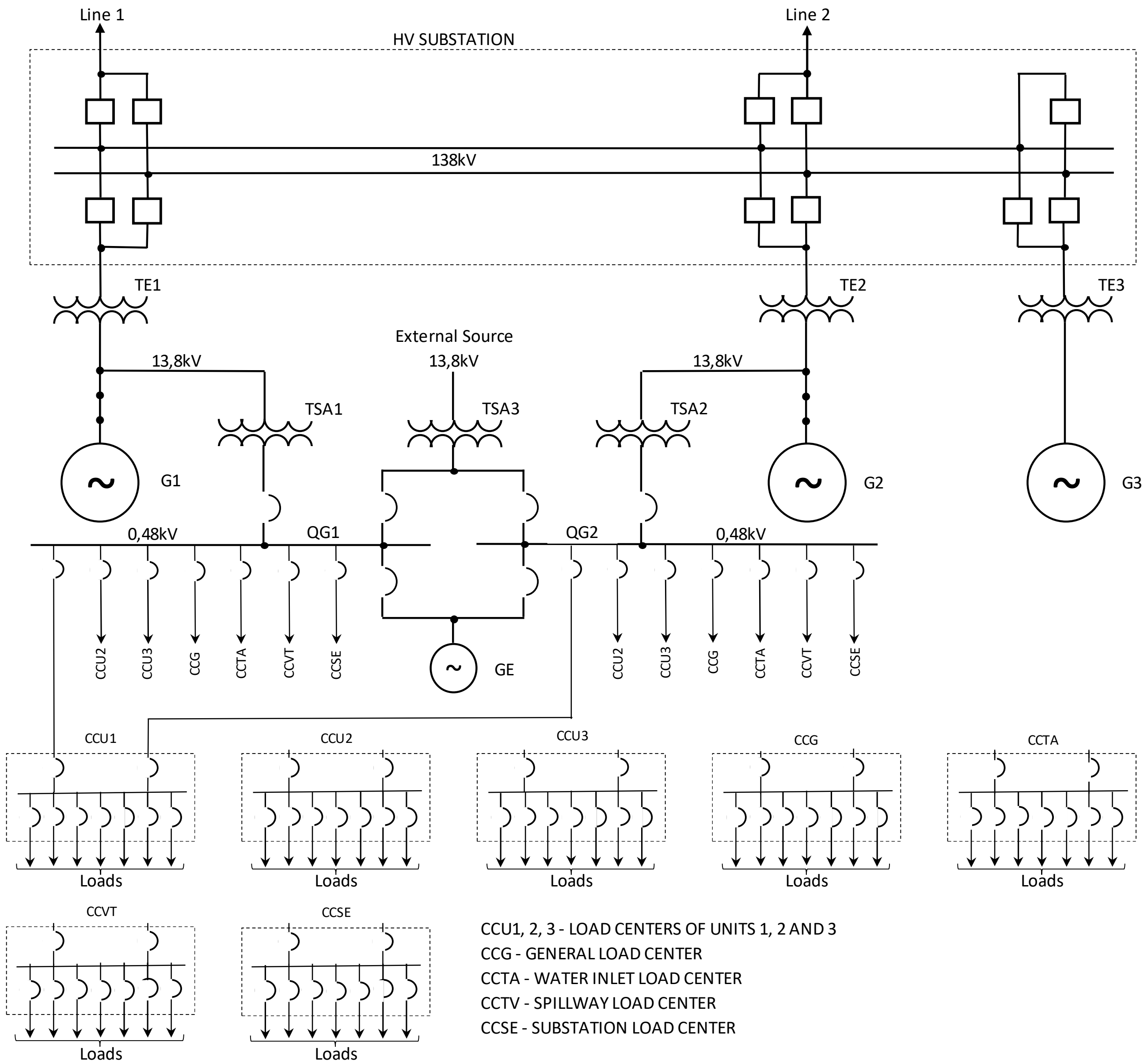
The system configuration information, loads data, power of auxiliary services transformers, step-up transformers, generators units and emergency generator set are fictitious and will be considered as being used and calculated in the sizing of the Technical Newsletter IT.EL.SA. CA.02 -Power Transformers and Emergency Generator Set - Sizing.

## 4 - DEFINITIONS

For the applications of this technical information, the following definitions of equipment and systems will be adopted:

### 4.1 - System Configuration

As there is no standard configuration for the electrical system of hydroelectric plants, for the examples of this document will be considered the configuration of the following figure, which was the configuration adopted for the sizing of the transformers of auxiliary services and emergency generator set.



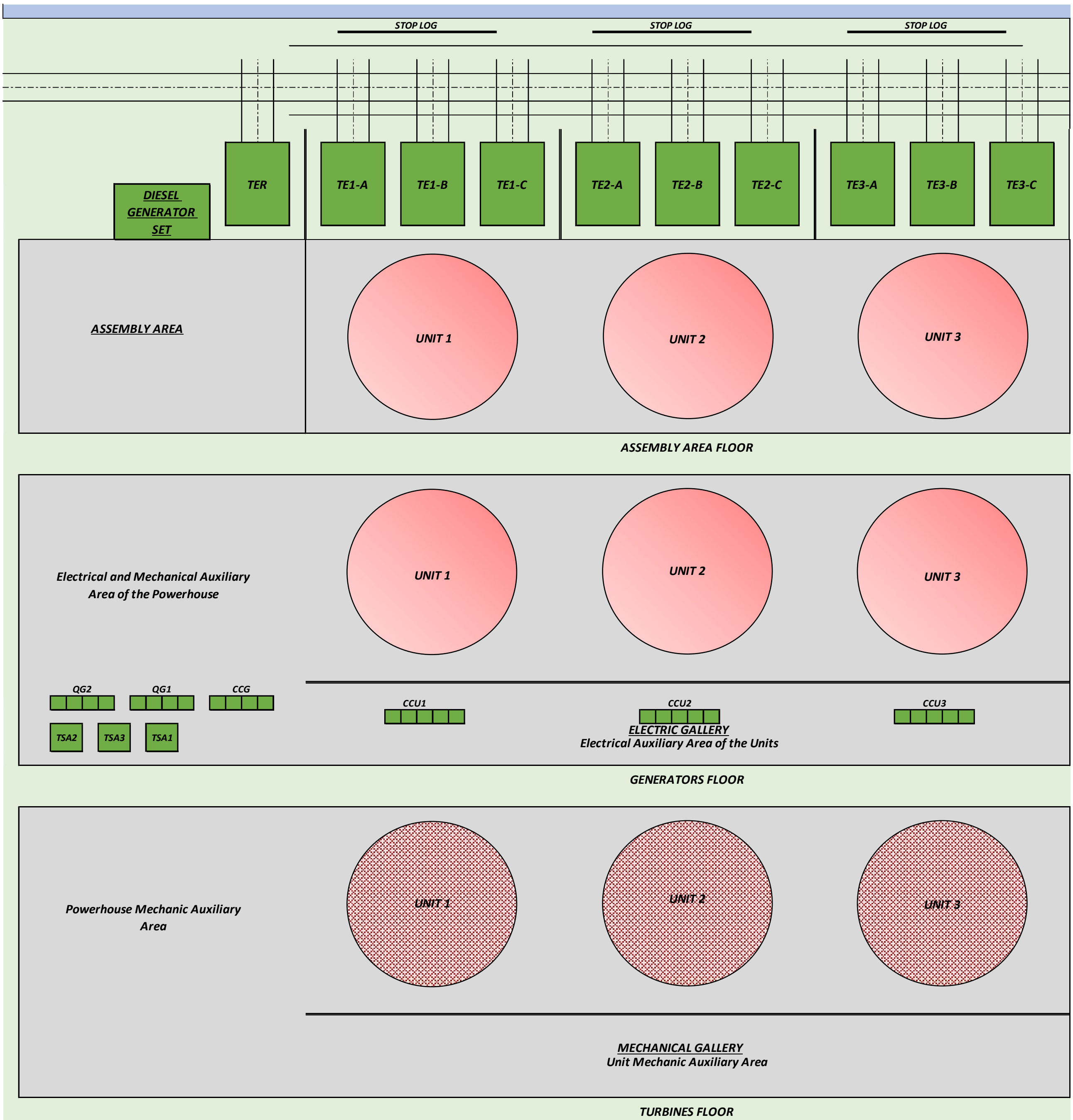

### 4.2 - Physical Arrangement of the Plant

For the sizing of the loads' feeders, it is important to define the arrangement of the Powerhouse and, based on this arrangement, define the paths and lengths of the circuits, and perform the calculations.

For this technical information, each unit's span will be considered with 20m x 20m; the electrical and mechanical galleries 8m wide; the mounting area 20x30m.

The arrangements of the Water Intake, Spillway and Substation depend, among other factors, on the arrangement of the Plant, the location of the transmission lines, size of the reservoir, height of the dam etc. However, except for distances to the Powerhouse, the arrangements will not be considered relevant to the purpose of this work.

The physical arrangement of the Powerhouse, schematically, to meet the objectives of this newsletter, is indicated in the following figure:




## 4.3 - High Voltage System

The high voltage system is not the subject of the studies, but for the purpose of the examples in this document, the short circuit power of the 138kV system will be 5000MVA.

The operating range of the voltage in the 138kV system will be considered within the values defined in the following table:

**Tabela 2** – Pontos de conexão em Tensão Nominal igual ou superior a 69 kV e inferior a 230 kV

| Tensão de Atendimento (TA) | Faixa de Variação da Tensão de Leitura (TL) em Relação à Tensão de Referência (TR) |
|---|---|
| Adequada | 0,95TR≤TL≤1,05TR |
| Precária | 0,90TR≤TL<0,95TR ou 1,05TR<TL≤1,07TR |
| Crítica | TL<0,90TR ou TL>1,07TR |

### 4.4 - External Source

The rated voltage of the external source, which powers the TSA3 auxiliary services transformer, will be considered as 13.8kV. If the short-circuit power of the external source is unknown, it will be considered infinite.

### 4.5 - Medium Voltage

The rated voltage of the medium voltage system will be 13.8kV and the voltage operating range of the plant generation can be calculated as defined in the technical information TE.EL.SA.CA.03 Hydroelectric Power Plant - Calculation of Generation Voltage and aid of the PL.EL.SA Worksheet. CA.06 Hydroelectric Power Plant - Calculation of Generation Voltage. However, for the purpose of the examples of this informative, the voltage operating range of the system, both generation and of the external source of 13.8kV, will be considered the one defined in Table 3 of ANEEL.

**Tabela 3** – Pontos de conexão em Tensão Nominal superior a 1 kV e inferior a 69 kV

| Tensão de Atendimento (TA) | Faixa de Variação da Tensão de Leitura (TL) em Relação à Tensão de Referência (TR) |
|---|---|
| Adequada | 0,93TR≤TL≤1,05TR |
| Precária | 0,90TR≤TL<0,93TR |
| Crítica | TL<0,90TR ou TL>1,05TR |

### 4.6 - Generating Units

The generating units G1, G2 and G3 will be considered with rated power of 100MVA, and subtransient reactance X"d=20%.

### 4.7 - Step-up Transformers

The step-up transformers TE1, TE2 and TE3 will be considered with rated power of 60/80/100MVA (ONAN/ONAF1/ONAF2), 13.8kV – 138kV (± 2 x 2.5%) and impedance of 10% referred to the power of 60MVA. However, physically, in the arrangement it will be indicated that there are three single-phase transformers of 20/26.66/33.33MVA.

### 4.8 - Auxiliary Service Transformers

Auxiliary service transformers TSA1, TSA2 and TSA3 shall be considered to have the following characteristics:

Type: Three-phase dry (ANAN)

Rated Power: 1000kVA

Rated Voltages: 13.8kV (± 2 x 2.5%) - 480V

Rated Frequency: 60Hz

Rated Impedance: 6%

Winding connection: Dyn

### 4.9 - Emergency Diesel Generator Set

Rated Voltage: 480V

Rated Frequency: 60Hz

Number of poles: 4

Continuous Rated Power (Prime): 360kVA

Emergency Power (Stand By): 396kVA

Transient Reactance: 8.71%

Operating Voltage: 506V

### 4.10 - Alternator of the Emergency Diesel Generator Set

Manufacturer: WEG

Model: 280MI40AI

Rated Power: 605kVA

Rated Voltage: 480V

Rated Frequency: 60Hz

Operating Voltage: 506V

Transient Reactance in 480V: 11.60%

Subtransient Reactance at 480V: 8.41%

### 4.11 - Low Voltage System

The characteristics of the low-voltage system shall be deemed to be:

Rated Voltage: 480V, ±10%

Three-phase system: solidly grounded star

Rated Frequency: 60Hz

### 4.12 - General Equipment

Equipment in general (heating resistors, battery chargers, gantries etc.) will have the following nominal characteristics:

Rated Voltage: 480V

Rated Frequency: 60Hz

Maximum Voltage: 528V (480V, +10%)

Minimum Voltage: 432V (480V, -10%)

Exceptional Minimum Voltage: 408V (480V, -15%)

### 4.13 - Three-phase motors

Three-phase induction motors shall have the following characteristics:

Rated Voltage: 460V

Rated Frequency: 60Hz

Maximum Voltage: 506V (460V, +10%)

Normal Minimum Voltage: 437V (460V, -5%)

Exceptional Minimum Voltage: 414V (460V, -10%)

Minimum Starting Voltage: 391V (460V, -15%)

Insulation Class: F with temperature elevation of 80ºC (class B). This feature will allow the motors to operate at voltages higher or lower than those normally specified,

The rated currents of the motors shall be as indicated in the following table for the rated voltage of 460; the starting currents 8 times the rated current (except the 100hp motor which will be 1054A), with power factor 0.3. In operation the power factor of all motors will be considered 0.85.

| *Power (hp)* | 0,5 | 0,75 | 1 | 1,5 | 3 | 5 | 7,5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 | 60 | 75 | 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *In (A)* | 1,1 | 1,6 | 2,1 | 3,0 | 4,8 | 7,6 | 11 | 14 | 21 | 27 | 34 | 40 | 52 | 65 | 77 | 96 | 124 |
| *Ip (A)* | 8,8 | 12,8 | 16,8 | 24,0 | 38,4 | 60,8 | 88 | 112 | 168 | 216 | 272 | 320 | 416 | 520 | 616 | 768 | 1054 |

### 4.14 - Control Transformers

Ratio: 480-120V

Nominal Ratio: 460-115V

### 4.15 - Contactors and Auxiliary Relays

Rated Voltage: 115V

Voltage Variation: +10% (126.5V), -15% (97.75V)

### 4.16 - Constant Loads

The constant loads are the loads whose consumption practically does not change with the variation of the voltage. In these cases, are the three-phase induction motors, battery chargers, communication systems etc. For the calculation of voltage drops, the data of these loads shall be considered as being:

Rated Voltage: 460V

Power Factor: 0.85

Note: The rated voltage of the constant loads is being considered as 460V because it is the nominal voltage of the motors, which make up most of the loads of the plant. The rated voltage of the battery chargers is 480V, but for the purpose of the voltage drop, the value of the rated voltage will not be relevant. However, the fact that the nominal voltage of battery chargers is considered 460V in the calculations of the voltage drop will not imply in changing its other characteristics, such as the overvoltage limits.

### 4.17 - Variable Loads

Variable loads are load whose consumption changes with the variation of the voltage. In these cases, there are loads such as heating resistors, who's current varies with the voltage variation. For the calculation of voltage drops, the data of these loads shall be considered as being:

Rated Voltage: 480V

Power Factor: 0.90

Note: In the case of loads considered variable, with different nominal voltages, the total power value of all these loads should be referred to the same nominal voltage. For example, a heating resistor of 10kW, with a rated voltage of 440V, should be considered as 11.9kW in 480V, with a power factor of 1.0.

### 4.18 - Maximum Plant Load

Constant Load: 650kVA, with power factor 0.85.

General Loads: 150kVA, with power factor 0.90.

### 4.19 - Maximum Emergency Load

Constant Load: 310kVA, with power factor 0.85.

General Loads: 50kVA, with power factor 0.90.

## 5 - APPLICATIONS

The applications have the purpose of using, in the examples considered, the technical and, theoretical information and spreadsheets related in the reference documents.

The tendency to be conservative often leads us to oversize the components of the installation and, other times, applying the strict wording of the standards, to undersize or oversize the systems and components.

When a new design is drawn up, the system configuration is defined, and the powers of the electric charges are estimated based on preliminary data. The equipment and components of the installation, mainly cables, dimensions of frames and powers of the transformers, are being dimensioned and defined, initially, with this preliminary information. It happens that, during the development of the project, the actual loads are being defined and it is necessary to continuously verify whether, due to the new information, it is necessary to change or adapt the definitions adopted. Usually, when the loads are defined by experienced professionals, it is only necessary to adapt the specific circuits of some components, because the estimated powers of the loads are, in general, very close to the real ones, some a little above or a little below, but in general within the initial forecast.

As in all installations there will always be redundancy where there is a main transformer and another reserve and, if each transformer is sized to meet all loads in the most severe operating conditions of the installation, the load normally applied to one of the transformers will be well below 50% of the nominal power of the transformer.

In this informative, applications will be limited to making calculations of the most common situations, because sizing in detail all circuits and analyzing all operating conditions is not the objective of this document. However, to consolidate some definitions, it will be necessary to address some concepts, which will be analyzed in more depth.

## 5.1 - Voltage in Transformers

To calculate the voltage at the secondary terminals of a transformer it is necessary to define the nominal power of the transformer, the nominal impedance, the nominal primary and secondary voltages, the value of the primary voltage of the source, the derivations of the high voltage winding, the applied loads, and their operating conditions.

### 5.1.1 - Rated Power of the Transformer

The rated power of the auxiliary service transformer depends on the loads fed and its operating conditions. This aspect has been covered in detail in the technical information IT.EL.SA.CA.02 Power Transformer and Emergency Diesel Generator Set - Sizing

For transformers with the same impedance value, the use of higher powers than calculated can bring a small advantage with the reduction of the voltage drop. For example, if we consider:

Rated transformer power 1000kVA

Nominal transformer impedance 6%

Rated voltages: 13.8kV (±2 x 2.5%) - 480V

Voltage considered at source: 14.49kV (13.8kV, +5%)

Tap used: 13.8kV

Constant Load: 650kVA, rated voltage 460V, with power factor 0.85.

Variable Loads: 150kVA, rated voltage 480V, with power factor 0.9.

How to check using the spreadsheet TE.EL.SA.AC.01 POWER TRANSFORMERS - Voltage Calculation in the Terminals, the voltage in the transformer terminals for the maximum load of the plant considered, will be 489.00V.

| SYSTEM DATA | | | |
|---|---|---|---|
| Transformer | $V_{P_n}$ | Rated Primary Voltage of Transformer (kV) | 13,8 |
| | $V_{S_n}$ | Rated Secondary Voltage of Transformer (V) | 480 |
| | $P_{TF_n}$ | Rated Power of Transformer (kVA) | 1000 |
| | $Z_n$ | Rated Impedance of Transformer (%) | 6 |
| | $R_n$ | Rated Resistence of Transformer (%) | 1 |
| | $V_P$ | Primary Voltage on Transformer (kV) | 14,49 |
| | $k$ | Tap Voltage Used of Transformer (pu) | 1 |
| Loads Data | $Pc_{Kn}$ | Rated Power of Constant Load (kVA) | 650 |
| | $Vc_{Kn}$ | Rated Voltage of Constant Load (V) | 460 |
| | $FPc_K$ | Power Factor of Constant Load | 0,85 |
| | $Pc_{Vn}$ | Rated Power of Variable Load (kVA) | 150 |
| | $Vc_{Vn}$ | Rated Voltage of Variable Load (V) | 480 |
| | $FPc_V$ | Power Factor of Variable Load | 0,9 |
| | $VM_{pn}$ | Rated Voltage of Motor(s) (V) | |
| | $IM_{pn}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FPM_p$ | Power factor of Motor(s) at Starting | |

| | | |
|---|---|---|
| $V_{T_s}$ | *Voltage on Secondary Terminals of Transformer (V)* | 489,00 |

If, instead of a 1000kVA transformer we use a 1500kVA transformer, the voltage will be 494.14V.

| 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) | 1500 |
| | $Z_n$ | Rated Impedance of Transformer (%) | 6 |
| | $R_n$ | Rated Resistence of Transformer (%) | 1 |
| | $VP$ | Primary Voltage on Transformer (kV) | 14,49 |
| | $k$ | Tap Voltage Used of Transformer (pu) | 1 |
| Loads Data | $Pc_{Kn}$ | Rated Power of Constant Load (kVA) | 650 |
| | $Vc_{Kn}$ | Rated Voltage of Constant Load (V) | 460 |
| | $FPc_K$ | Power Factor of Constant Load | 0,85 |
| | $Pc_{Vn}$ | Rated Power of Variable Load (kVA) | 150 |
| | $Vc_{Vn}$ | Rated Voltage of Variable Load (V) | 480 |
| | $FPc_V$ | Power Factor of Variable Load | 0,9 |
| | $VM_{pn}$ | Rated Voltage of Motor(s) (V) | |
| | $IM_{pn}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FPM_p$ | Power factor of Motor(s) at Starting | |

| | | |
|---|---|---|
| $VT_s$ | *Voltage on Secondary Terminals of Transformer (V)* | 494,14 |

For the same conditions, the voltage that was 489.00V (480V, +1.7%) for the 1000kVA transformer, will become 494.14V (480V, +2.9%) for the 1500kVA transformer, which corresponds to a difference of 5.14V.

5.1.2 - Rated Impedance Transformer

The rated impedance of transformers is defined as a function of the type of transformer. For example, for dry transformers in the considered powers the impedance is 6%, but for transformers in oil it can be 5%. The exact impedance is set during factory tests and is recorded on the transformer nameplate.

5.1.3 - Rated Voltages of Transformers

The rated voltages of the transformers are defined by the project according to the information of the Customer and the characteristics of the installation.

5.1.4 - High Voltage Winding Tap

The tap used from the high voltage winding of the auxiliary services transformer shall be the subject of the design evaluation. In principle, this value shall ensure that the maximum voltage of any load does not exceed its permissible limits.

The rated voltage of the secondary of the control transformers is 115V, and for the 4:1 ratio, the 460-115V transformers, installed in 480V systems, will operate as 480-120V.

Considering the maximum permissible voltages defined for the equipment, the maximum voltage of 506V will meet the maximum voltages of all components, as listed below:

- General loads: 528V (480V, +10%)
- Motors: 506V (460V, +10%)
- Control Transformers: 506V, i.e., 506V (460V, +10%) -126.5V (115V, +10%)
- Contactors and Auxiliary Relays: 126.5V (115V, +10%)

For the maximum voltage in the secondary of the auxiliary services transformer to be 506V, with the maximum system voltage of 13.8kV at 14.49kV (1.05 x 13.8kV), the derivation to be used must be the nominal one, that is, the derivation corresponding to 13,800V.

The derivation to be used can be calculated by the formula:

$$Tap = V_{MMT} x \frac{V_{NBT}}{V_{MBT}}$$

Where:

$Tap - Transformer\ Primary\ Winding\ Tap\ (V)$

$V_{MMT} - Maximun\ Voltage\ of\ Medium\ Voltage\ System\ (V)$

$V_{NBT} - Rated\ Voltage\ of\ Winding\ Transformer\ Secondary\ (V)$

$V_{MBT} - Maximun\ Voltage\ of\ Winding\ Transformer\ Secondary\ (V)$

Calculating the value of the voltage of the tap of the primary winding we have:

$$Tap = 14.490 x \frac{480}{506} = 13.745V$$

Since the leads of the primary transformer winding are 13,110V-13,455V-13,800V-14,145V-14490V, the nearest lead to 13,745V is that of 13,800V.

Using the 13,800V derivation of the primary winding, with the maximum voltage in the primary of 14,490V, the maximum voltage in the secondary of the transformer, with no load, will be:

$$V_{MBT} = V_{MMT} x \frac{V_{NBT}}{Tap}$$

That is

$$V_{MBT} = 14.490 x \frac{480}{13.800} = 504V$$

The use of a tap other than that recommended can be defined if, with the minimum load of the installation, it can be ensured that the maximum voltage of the equipment will not be exceeded.

The most appropriate derivation can also be defined by the personnel of the operation of the installations, depending on the actual operating conditions of the loads and the behavior of the supply voltages of the transformers.

5.1.5 - Transformer Power Voltage

If the power supply is a concessionaire, which may be the case of the external source, the voltage must be within the contractually defined limits.

In this information, the 13800V derivation of the high voltage winding of the auxiliary services transformer will be used. However, to define the generation voltage more precisely, which is usually used to power the auxiliary services, the spreadsheet can be used PL.EL.SA.CA.06 Hydroelectric Power Plant - Generation Voltage Calculation, in according to the with the informative TE.EL.SA.CA.03 Hydroelectric Power Plant - Generation Voltage Calculation.

Below will be made some simulations considering that each generating unit provides the power of 100MVA with power factor 1.00, with the voltage in the AT substation in the appropriate voltage range, that is, from 95% (131.1kV) to 105% (144.9kV) of the nominal voltage, for the leads of the elevator transformer in 138kV±2.5%. Other values can be simulated by the user to define the most likely voltage range of generation operation, to define the derivation to be used in the high voltage winding of the auxiliary services transformer.

For the voltage of 131.1kV in the substation, and tap of the high voltage winding of the step-up transformer in the tap of 138kV-2.5%, the voltage in the generation will be:

| SYSTEM DATA | | | |
|---|---|---|---|
| Generation, Substation and Step-up Transformer Data | $VP_{TEn}$ | Rated Primary Voltage of Transformer (kV) | 13,8 |
| | $VS_{TEn}$ | Rated Secondary Voltage of Transformer (kV) | 138 |
| | $P_{TEn}$ | Rated Power of Transformer (MVA) | 60 |
| | $Z_n$ | Rated Transformer Impedance (%) | 10 |
| | $R_n$ | Rated Resistance of Transformer (%) | 1 |
| | $k$ | Secondary Used Tap Voltage (pu) | 0,975 |
| | $P_G$ | Total Power Passing Through the Transformer (MVA) | 100 |
| | $FP$ | Total Generation Power Factor | 1 |
| | $V_{Gn}$ | Rated Generation Voltage (kV) | 13,8 |
| | $V_{SE}$ | Voltage at the Associated Substation (kV) | 131,1 |
| | | $V_G$ (kV) | 13,88 |
| | | $V_G$ (%$V_{Gn}$) | 100,60 |

For the voltage of 131.1kV in the substation, and tap of the high voltage winding of the step-up transformer in the 138kV tap, the voltage in the generation will be:

| SYSTEM DATA | | | |
|---|---|---|---|
| Generation, Substation and Step-up Transformer Data | $VP_{TEn}$ | Rated Primary Voltage of Transformer (kV) | 13,8 |
| | $VS_{TEn}$ | Rated Secondary Voltage of Transformer (kV) | 138 |
| | $P_{TEn}$ | Rated Power of Transformer (MVA) | 60 |
| | $Z_n$ | Rated Transformer Impedance (%) | 10 |
| | $R_n$ | Rated Resistance of Transformer (%) | 1 |
| | $k$ | Secondary Used Tap Voltage (pu) | 1 |
| | $P_G$ | Total Power Passing Through the Transformer (MVA) | 100 |
| | $FP$ | Total Generation Power Factor | 1 |
| | $V_{Gn}$ | Rated Generation Voltage (kV) | 13,8 |
| | $V_{SE}$ | Voltage at the Associated Substation (kV) | 131,1 |
| | | $V_G$ (kV) | 13,57 |
| | | $V_G$ (%$V_{Gn}$) | 98,32 |

For the voltage of 131.1kV in the substation, and tap of the high voltage winding of the step-up transformer in the tap of 138kV + 2.5%, the voltage in the generation will be:

| SYSTEM DATA | | | |
|---|---|---|---|
| Generation, Substation and Step-up Transformer Data | $VP_{TEn}$ | Rated Primary Voltage of Transformer (kV) | 13,8 |
| | $VS_{TEn}$ | Rated Secondary Voltage of Transformer (kV) | 138 |
| | $P_{TEn}$ | Rated Power of Transformer (MVA) | 60 |
| | $Z_n$ | Rated Transformer Impedance (%) | 10 |
| | $R_n$ | Rated Resistance of Transformer (%) | 1 |
| | $k$ | Secondary Used Tap Voltage (pu) | 1,025 |
| | $P_G$ | Total Power Passing Through the Transformer (MVA) | 100 |
| | $FP$ | Total Generation Power Factor | 1 |
| | $V_{Gn}$ | Rated Generation Voltage (kV) | 13,8 |
| | $V_{SE}$ | Voltage at the Associated Substation (kV) | 131,1 |
| | | $V_G$ (kV) | 13,27 |
| | | $V_G$ (%$V_{Gn}$) | 96,16 |

For the voltage of 144.9kV in the substation, and tap of the high voltage winding of the step-up transformer in the tap of 138kV-2.5%, the voltage in the generation will be:

| SYSTEM DATA | | | |
|---|---|---|---|
| Generation, Substation and Step-up Transformer Data | $VP_{TEn}$ | Rated Primary Voltage of Transformer (kV) | 13,8 |
| | $VS_{TEn}$ | Rated Secondary Voltage of Transformer (kV) | 138 |
| | $P_{TEn}$ | Rated Power of Transformer (MVA) | 60 |
| | $Z_n$ | Rated Transformer Impedance (%) | 10 |
| | $R_n$ | Rated Resistance of Transformer (%) | 1 |
| | $k$ | Secondary Used Tap Voltage (pu) | 0,975 |
| | $P_G$ | Total Power Passing Through the Transformer (MVA) | 100 |
| | $FP$ | Total Generation Power Factor | 1 |
| | $V_{Gn}$ | Rated Generation Voltage (kV) | 13,8 |
| | $V_{SE}$ | Voltage at the Associated Substation (kV) | 144,9 |
| | | $V_G$ (kV) | 15,22 |
| | | $V_G$ (%$V_{Gn}$) | 110,32 |

For the voltage of 144.9kV in the substation, and tap of the high voltage winding of the step-up transformer in the 138kV tap, the voltage in the generation will be:

| SYSTEM DATA | | | |
|---|---|---|---|
| Generation, Substation and Step-up Transformer Data | $VP_{TEn}$ | Rated Primary Voltage of Transformer (kV) | 13,8 |
| | $VS_{TEn}$ | Rated Secondary Voltage of Transformer (kV) | 138 |
| | $P_{TEn}$ | Rated Power of Transformer (MVA) | 60 |
| | $Z_n$ | Rated Transformer Impedance (%) | 10 |
| | $R_n$ | Rated Resistance of Transformer (%) | 1 |
| | $k$ | Secondary Used Tap Voltage (pu) | 1 |
| | $P_G$ | Total Power Passing Through the Transformer (MVA) | 100 |
| | $FP$ | Total Generation Power Factor | 1 |
| | $V_{Gn}$ | Rated Generation Voltage (kV) | 13,8 |
| | $V_{SE}$ | Voltage at the Associated Substation (kV) | 144,9 |
| | | $V_G$ (kV) | 14,87 |
| | | $V_G$ (%$V_{Gn}$) | 107,75 |

For the voltage of 144.9kV in the substation, and tap of the high voltage winding of the step-up transformer in the tap of 138kV + 2.5%, the voltage in the generation will be:

| SYSTEM DATA | | | |
|---|---|---|---|
| Generation, Substation and Step-up Transformer Data | $VP_{TEn}$ | Rated Primary Voltage of Transformer (kV) | 13,8 |
| | $VS_{TEn}$ | Rated Secondary Voltage of Transformer (kV) | 138 |
| | $P_{TEn}$ | Rated Power of Transformer (MVA) | 60 |
| | $Z_n$ | Rated Transformer Impedance (%) | 10 |
| | $R_n$ | Rated Resistance of Transformer (%) | 1 |
| | $k$ | Secondary Used Tap Voltage (pu) | 1,025 |
| | $P_G$ | Total Power Passing Through the Transformer (MVA) | 100 |
| | $FP$ | Total Generation Power Factor | 1 |
| | $V_{Gn}$ | Rated Generation Voltage (kV) | 13,8 |
| | $V_{SE}$ | Voltage at the Associated Substation (kV) | 144,9 |
| | | $V_G$ (kV) | 14,53 |
| | | $V_G$ (%$V_{Gn}$) | 105,32 |

Based on simulations such as these, with the information of the expected voltage values in the substation and definition of the tap of the high voltage winding of the step-up transformer, the user will be able to define the tap value of the winding of the primary of the auxiliary services transformer more precisely.

In the above simulations, the generation voltages ranged from 13.27kV (96.16% VGn) to 14.53kV (105.32% VGn).

5.1.6 - Voltage Drops

The possible operating conditions of auxiliary service transformers can be evaluated using the spreadsheet PL.EL.SA.CA.01 - Power Transformers - Calculation of Voltage in Terminals. The detailed demonstrations of the formulas used for the preparation of the spreadsheets are in the technical information TE.EL.SA.CA.01 - Power Transformers - Calculation of Voltage in Terminals.

The calculations in this informative will analyze two operating conditions of the transformers, with two operating conditions of the loads. The first, which will be the normal operating condition, considers that two auxiliary service transformers feed all the loads of the plant. The second, which is the critical operating condition, considers that only a single transformer feeds all the loads of the plant.

The operating condition of the loads that will be considered, for the two operating conditions of the transformers, is the one that considers that the last load to be applied will be the engine start of 50hp (Fire Pump) or 100hp (Turbine Speed Regulator Oil Pump).

The first operating condition of the transformers considers that the maximum constant load of the plant is 650kVA (rated voltage 460V, power factor 0.85) and the variable 150kVA (rated voltage 480V, power factor 0.90); that the load is normally fed by two transformers, that is, each transformer feeds, theoretically, half of the load. The constant load that is of $650kVA/2 = 325kVA$ (rated voltage 460V, power factor 0.85) and the variable load which is $150kVA/2 = 75kVA$ (rated voltage 480V, power factor 0.90); that a transformer can power the entire load of the plant; that in the most severe condition, the 100hp or 50hp engines may be the last loads to be powered.

The second operating condition of the transformers considers that the maximum constant load of the plant is 650kVA (nominal voltage 460V, power factor 0.85) and the variable 150kVA (nominal voltage 480V, power factor 0.90); that the load is normally fed by a single transformer, that is, the transformer feeds the constant load is 650kVA (nominal voltage 460V, power factor 0.85) and the variable 150kVA (nominal voltage 480V, power factor 0.90); that in the most severe condition, 100hp or 50hp engines may be the last loads to be powered.

The voltage values calculated, using the spreadsheet, for all possible voltage values in the primary of the transformers for tap of the primary winding in 13800V, are those indicated in the table below, where it is verified, for example, that:

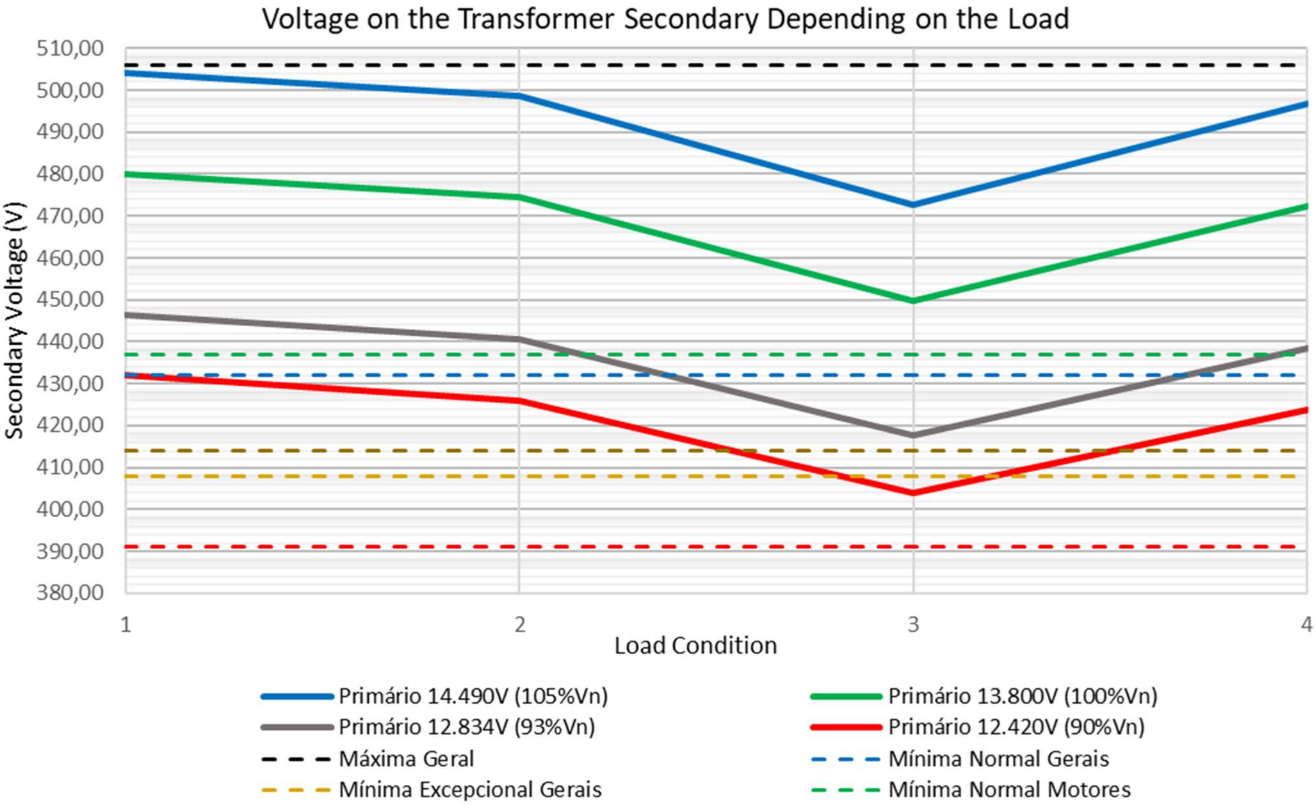
- In the first condition, where two auxiliary service transformers feed all the loads of the plant; with the primary voltage of 12,834V, with constant initial load of 275kVA (rated voltage 460V, power factor 0.85) and variable load of 75kVA (rated voltage 480V, power factor 0.90), during the motor start of 50hp, the voltage at the transformer terminals drops from 439.46V to 427.83V and then stabilizes at 438.38V.

- In the second condition, that only a single transformer feeds all the loads of the plant, with the primary voltage of 12,834V, with constant initial load of 600kVA (rated voltage 460V, power factor 0.85) and variable load of 150kVA (rated voltage 480V, power factor 0.90), during the motor start of 50hp, the voltage in the transformer terminals drops from 431.08V to 419.47V and then stabilizes at 429.94V.

| Primary Voltage (V) | Secondary Voltage (V) | | | | | |
|---|---|---|---|---|---|---|
| | No Load | Loads | | | | |
| | | Initial | | +Start of Motor (cv) | Final | |
| | | Constant (kVA) | Variable (kVA) | | Constant (kVA) | Variable (kVA) |
| 14.490 | 504,00 | 550,00 | 150,00 | 100 | 650,00 | 150,00 |
| | | 490,97 | | 465,12 | 489,00 | |
| | | 600,00 | 150,00 | 50 | | |
| | | 489,99 | | 476,89 | | |
| | | 225,00 | 75,00 | 100 | 325,00 | 75,00 |
| | | 498,53 | | 472,63 | 496,65 | |
| | | 275,00 | 75,00 | 50 | | |
| | | 497,59 | | 484,47 | | |
| 13.800 | 480,00 | 550,00 | 150,00 | 100 | 650,00 | 150,00 |
| | | 466,54 | | 441,91 | 464,45 | |
| | | 600,00 | 150,00 | 50 | | |
| | | 465,50 | | 453,02 | | |
| | | 225,00 | 75,00 | 100 | 325,00 | 75,00 |
| | | 474,38 | | 449,71 | 472,40 | |
| | | 275,00 | 75,00 | 50 | | |
| | | 473,39 | | 460,89 | | |
| 12.834 | 446,40 | 550,00 | 150,00 | 100 | 650,00 | 150,00 |
| | | 432,22 | | 409,29 | 429,94 | |
| | | 600,00 | 150,00 | 50 | | |
| | | 431,08 | | 419,47 | | |
| | | 225,00 | 75,00 | 100 | 325,00 | 75,00 |
| | | 440,53 | | 417,57 | 438,38 | |
| | | 275,00 | 75,00 | 50 | | |
| | | 439,46 | | 427,83 | | |
| 12.420 | 432,00 | 550,00 | 150,00 | 100 | 650,00 | 150,00 |
| | | 417,46 | | 395,26 | 415,09 | |
| | | 600,00 | 150,00 | 50 | | |
| | | 416,28 | | 405,03 | | |
| | | 225,00 | 75,00 | 100 | 325,00 | 75,00 |
| | | 426,00 | | 403,79 | 423,78 | |
| | | 275,00 | 75,00 | 50 | | |
| | | 424,90 | | 413,64 | | |

Still based on the data in the table, considering two transformers in the tap of the primary winding in 13800V, feeding the constant initial load of 550kVA and variable load of 150kVA, with the 100hp motor starting, that is, considering a transformer feeding, theoretically, 225kVA of constant load and 75kVA of variable load, and the start of the motor of 100hp occur in one of them, We have the following table and corresponding graph:

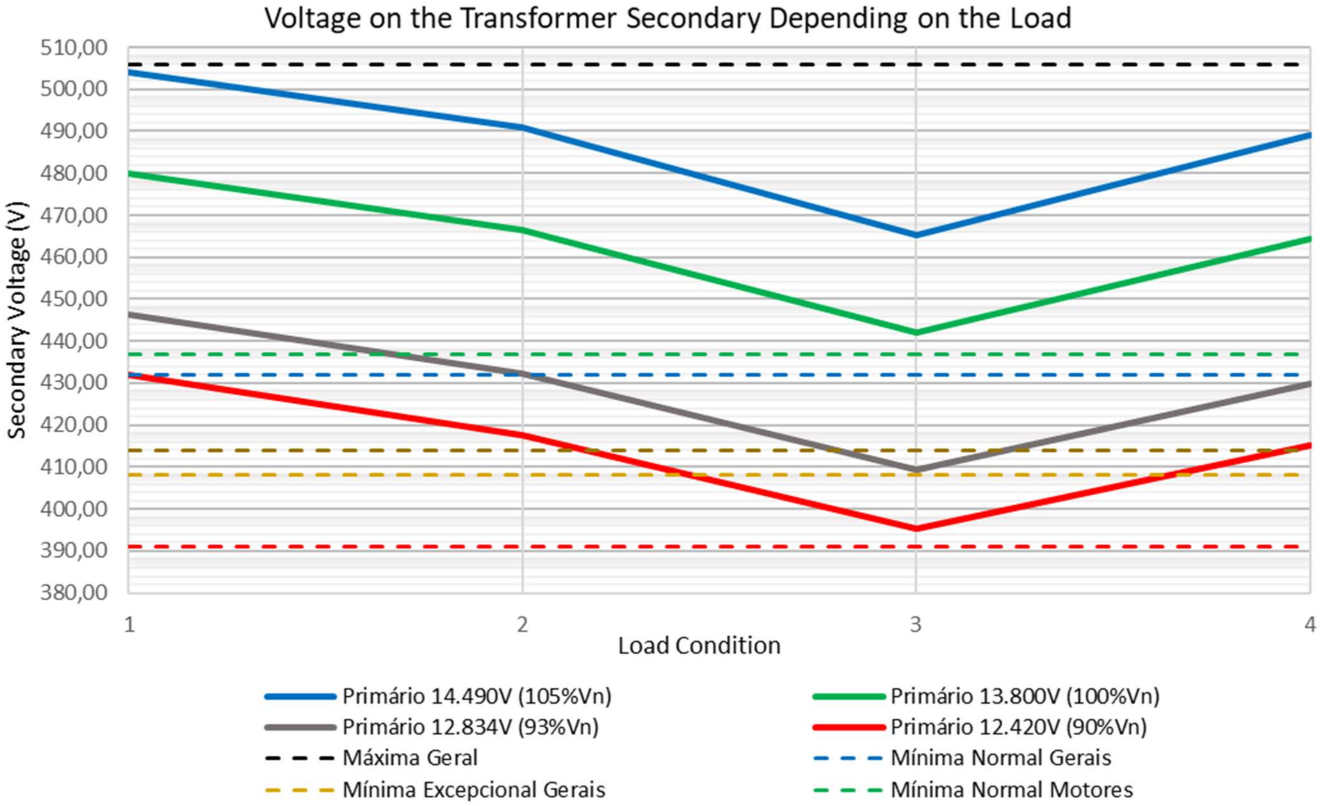
| Source | No Load | Initial Load | initial Load + Motor Starting | Final |
|---|---|---|---|---|
| Primary 14.490V (105%Vn) | 504,00 | 498,53 | 472,63 | 496,65 |
| Primary 13.800V (100%Vn) | 480,00 | 474,38 | 449,71 | 472,40 |
| Primary 12.834V (93%Vn) | 446,40 | 440,53 | 417,57 | 438,38 |
| Primary 12.420V (90%Vn) | 432,00 | 426,00 | 403,79 | 423,80 |
| Maximum General | 506,00 | 506,00 | 506,00 | 506,00 |
| Minimum Normal General | 432,00 | 432,00 | 432,00 | 432,00 |
| General Exceptional Minimun | 408,00 | 408,00 | 408,00 | 408,00 |
| Minimum Normal Motors | 437,00 | 437,00 | 437,00 | 437,00 |
| Minimum Exceptional Motors | 414,00 | 414,00 | 414,00 | 414,00 |
| Minimum Start Motors | 391,00 | 391,00 | 391,00 | 391,00 |




It is observed that if the voltage of the source of the primary transformer is within the appropriate voltage limit (from 93 to 105% of the nominal voltage) or precarious (from 90 to 93% of the nominal voltage), the system will operate normally, except during the start of the 100hp motor, when the voltage falls, transiently, below the minimum normal values of the general loads (480V, -10%) and minimum normal operation of the motors (460V, -5%).

Considering a single transformer feeding the constant initial load of 550kVA (rated voltage 460V, power factor 0.85) and variable load of 150kVA (rated voltage 480V, power factor 0.90), with the 100hp motor starting, we have the following graph:

| Source | No Load | Initial Load | initial Load + Motor Starting | Final |
|---|---|---|---|---|
| Primary 14.490V (105%Vn) | 504,00 | 490,90 | 465,12 | 489,00 |
| Primary 13.800V (100%Vn) | 480,00 | 466,54 | 441,91 | 464,45 |
| Primary 12.834V (93%Vn) | 446,40 | 432,22 | 409,29 | 429,94 |
| Primary 12.420V (90%Vn) | 432,00 | 417,46 | 395,26 | 415,09 |
| Maximum General | 506,00 | 506,00 | 506,00 | 506,00 |
| Minimum Normal General | 432,00 | 432,00 | 432,00 | 432,00 |
| General Exceptional Minimum | 408,00 | 408,00 | 408,00 | 408,00 |
| Minimum Normal Motors | 437,00 | 437,00 | 437,00 | 437,00 |
| Minimum Exceptional Motors | 414,00 | 414,00 | 414,00 | 414,00 |
| Minimum Start Motors | 391,00 | 391,00 | 391,00 | 391,00 |




It is observed that if the voltage of the source of the transformer primary is within the appropriate voltage limit (from 93 to 105% of the nominal voltage), the system will operate normally, except during the start of the 100hp motor, when the voltage drops, transiently, below the minimum normal values of the general loads (480V, -10%) and exceptional minimum of operation of the motors (460V, -10%). However, during this transitional period, the voltage will remain above the exceptional minimum voltage of the general loads (480V, -15%). The fact that the voltage is below the minimum normal operating value of the motors (460V, - 5%) will be considered normal since the motors have Class F insulation but are designed to operate at Class B temperatures.

If the voltage of the primary source of the transformer is in the precarious voltage range (from 90 to 93% of the nominal voltage), during the start of the 100hp motor, the voltage drops, transiently, below the exceptional minimum values of the general loads (480V, -15%) and exceptional minimum of operation of the motors (460V, -10%). However, during this transitional period, the voltage will remain above the minimum starting voltage of the motors (460V, -15%). After the transitional period of the 100hp motor start, the voltage in the general loads will be above the exceptional minimum operating voltage of the motors (460V, -10%) and the exceptional minimum voltage of the general loads (480V, -15%).

### 5.2 - Emergency Diesel Generator Set

The emergency diesel generator set is planned to meet the emergency conditions of the plant. However, depending on its capacity and the needs of the operation of the plant, it may meet other loads not foreseen in the calculation memory.

Similarly, to the behavior of the transformer voltage, considering the actual data of the alternator, the following operating conditions will be evaluated:

In the first condition, that the group feeds a constant initial load of 260kVA (rated voltage 460V, power factor 0.85) and variable load of 50kVA (rated voltage 480V, power factor 0.90), during the motor start of 50hp, the voltage at the alternator terminals drops from 506V to 465.91V and then reestablishes itself at 506V.

| 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) | 605 |
| | | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 11,6 |
| Loads Data | Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 260 |
| | | $Vc_{kn}$ | 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) | 520 |
| | | $FPM_P$ | Power Factor of Motor(s) at Starting | 0,3 |

| | | |
|---|---|---|
| *Voltage at the Alternator Terminals (V)* | $V_{GT}$ (%) | **465,91** |

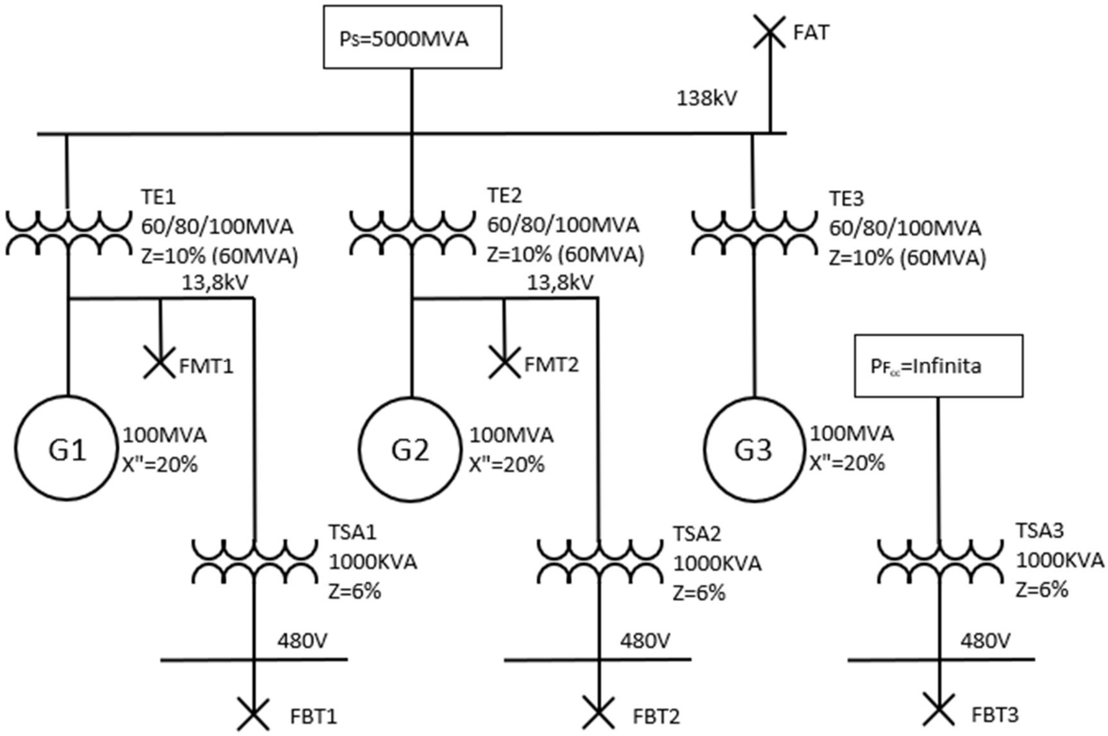
In the second condition, that the group feeds a constant initial load of 210kVA (rated voltage 460V, power factor 0.85) and variable load of 50kVA (rated voltage 480V, power factor 0.90), during the motor start of 100hp, the voltage at the alternator terminals drops from 506V to 431.00V and then reestablishes itself at 506V.

| 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) | 605 |
| | | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 11,6 |
| Loads Data | Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 260 |
| | | $Vc_{kn}$ | 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 |

| | | |
|---|---|---|
| *Voltage at the Alternator Terminals (V)* | $V_{GT}$ (%) | **430,45** |

**5.3 - Short Circuit Currents**

The three-phase short circuit currents will be calculated for the FAT points (138kV System); FMT1 and 2 (13.8kV systems); and FBT1, 2 and 3 (480V systems) indicated in the following figure:




The calculation of the short circuit currents at the various points of the installation will be done using the MVA method. This method, by Monn H. Yuen, was published by the IEEE in 1974. The white paper, IT.EL.SA. CA.03 Short Circuit - Calculation of Currents, details this method for symmetrical three-phase short circuit currents and its concepts will be applied to the plant system, according to its information and indicated in the single-line diagram.

Calculating the short circuit powers of each component we have:

$$P_{G1.2.3} = \frac{100}{20}x100 = 500MVA$$

$$P_{TE1,2,3} = \frac{60}{10}x100 = 600MVA$$

$$P_{TSA1,2,3} = \frac{1}{6}x100 = 16,7MVA$$

To calculate the equivalent, short-circuit power of sets in series the formula applies:

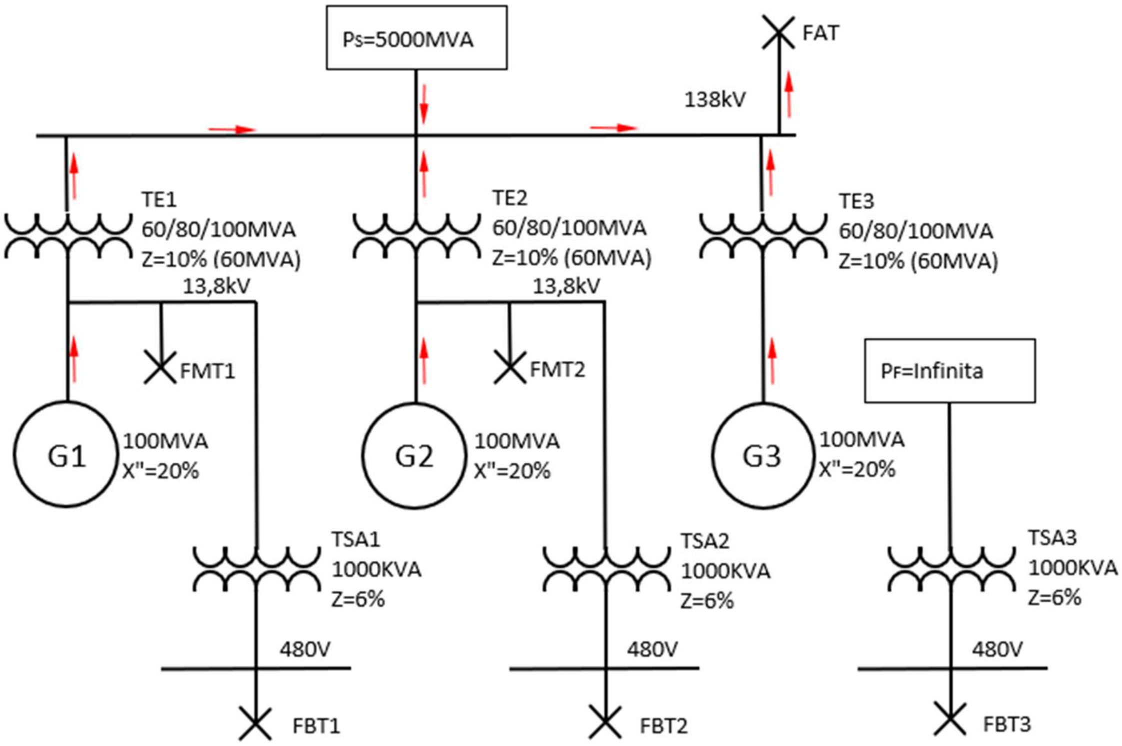
$$\boldsymbol{Pcc_T = \frac{1}{\frac{1}{Pcc_1} + \frac{1}{Pcc_2} + \frac{1}{Pcc_3} + \cdots + \frac{1}{Pcc_n}}}$$

To calculate the equivalent short circuit power of sets in parallel the formula applies:

$$\boldsymbol{Pcc_T = Pcc_1 + Pcc_2 + Pcc_3 + \cdots + Pcc_n}$$

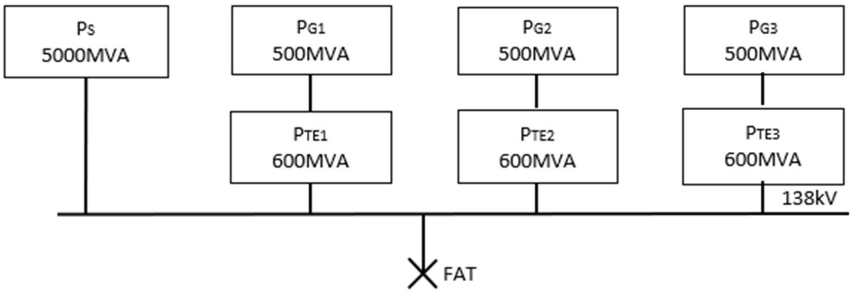
5.3.1 - 138kV System

For the 138kV system the calculation will be made on the Substation bus, represented by the FAT point in the figure below:



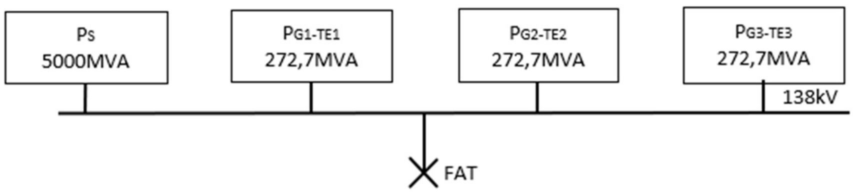

The arrows indicate the direction of the currents.

The block diagram below represents the system involved in the defect at the FAT point:




Calculating:

$$P_{G1-TE} = \frac{1}{\frac{1}{P_{G1}} + \frac{1}{P_{TE1}}} = P_{G2-TE} = P_{G3-TE} = \frac{1}{\frac{1}{500} + \frac{1}{600}} = 272,7MVA$$

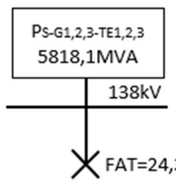



$$P_{S-G1,2,3-TE1,2,3} = P_S + P_{G1-TE} + P_{G2-TE}\ P_{G3-TE} = 5000 + 272,7 + 272,7 + 272,7$$

$$P_{S-G1,2,3-TE1,2,3} = 5818,1MVA$$

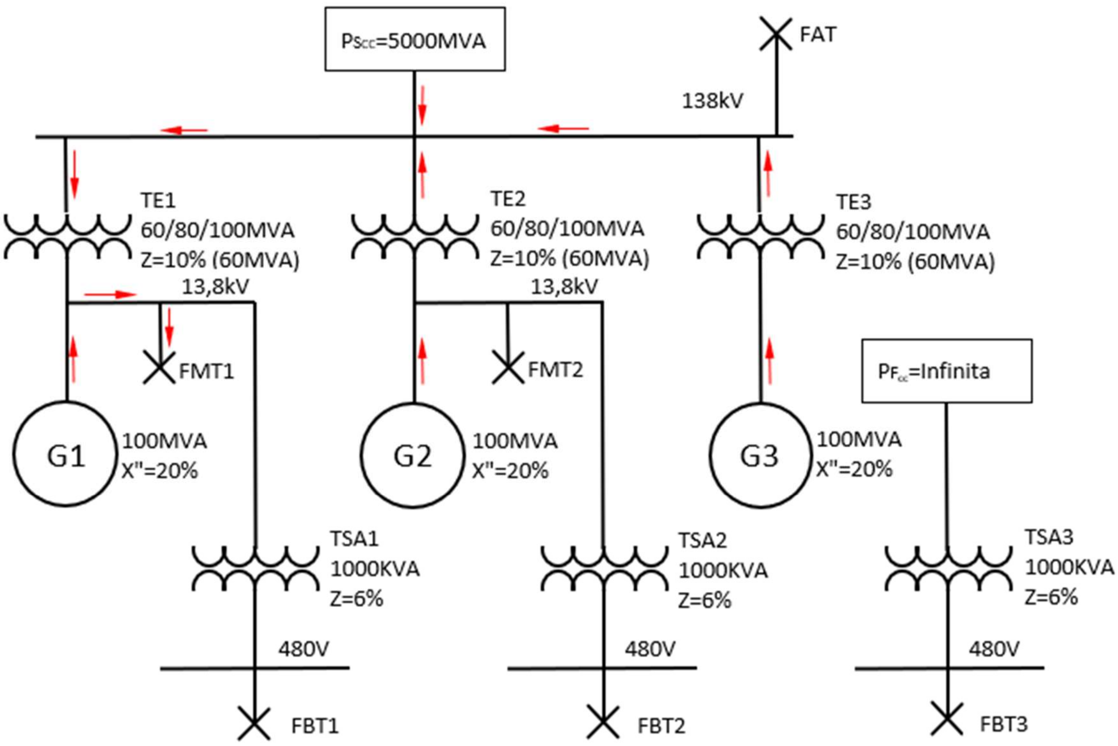
Which corresponds to a current.

$$I_{FAT} = \frac{5818,1}{\sqrt{3}.138} = 24,3kA$$

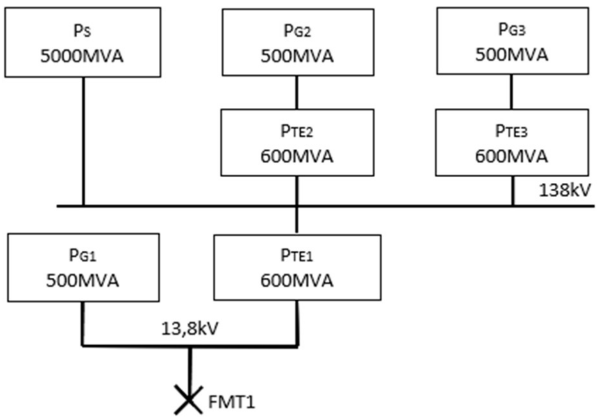


5.3.2 - 13.8kV System

The calculation of the short circuit currents in the 13.8kV system will be done for points FMT1 and 2

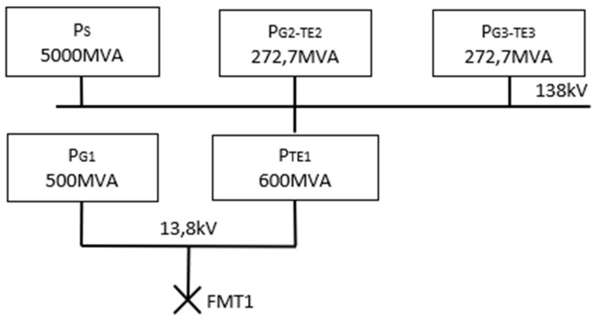



The following block diagram represents the system involved:

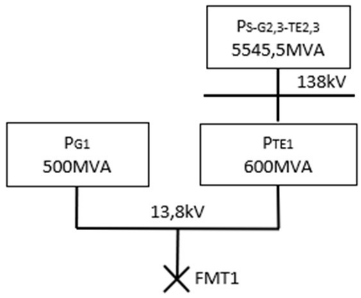



Calculating:

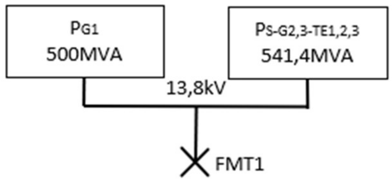
$$P_{G2-TE} = \frac{1}{\frac{1}{P_{G2}} + \frac{1}{P_{TE2}}} = P_{G3-TE3} = \frac{1}{\frac{1}{500} + \frac{1}{600}} = 272{,}7MVA$$




$$P_{S-G2,3-TE2,3} = P_S + P_{G2-TE2} + P_{G3-TE3} = 5000 + 272{,}7 + 272{,}7 = 5545{,}5MVA$$



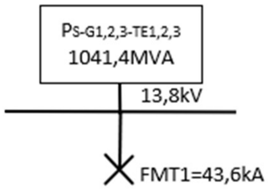

$$P_{S-G2,3-TE1,2,3} = \frac{1}{\frac{1}{P_{S-G2,3-TE2,3}} + \frac{1}{P_{TE}}} = \frac{1}{\frac{1}{5545,5} + \frac{1}{600}} = 541,4MVA$$




$$P_{S-G1,2,3-TE1,2,3} = P_{S-G2,3-TE1,2,3} + P_{G1} = 541,4 + 500 = 1041,4MVA$$

Which corresponds to a current of:

$$I_{FMT1} = \frac{1041,4}{\sqrt{3}X13,8} = I_{FMT2} = 43,6kA$$



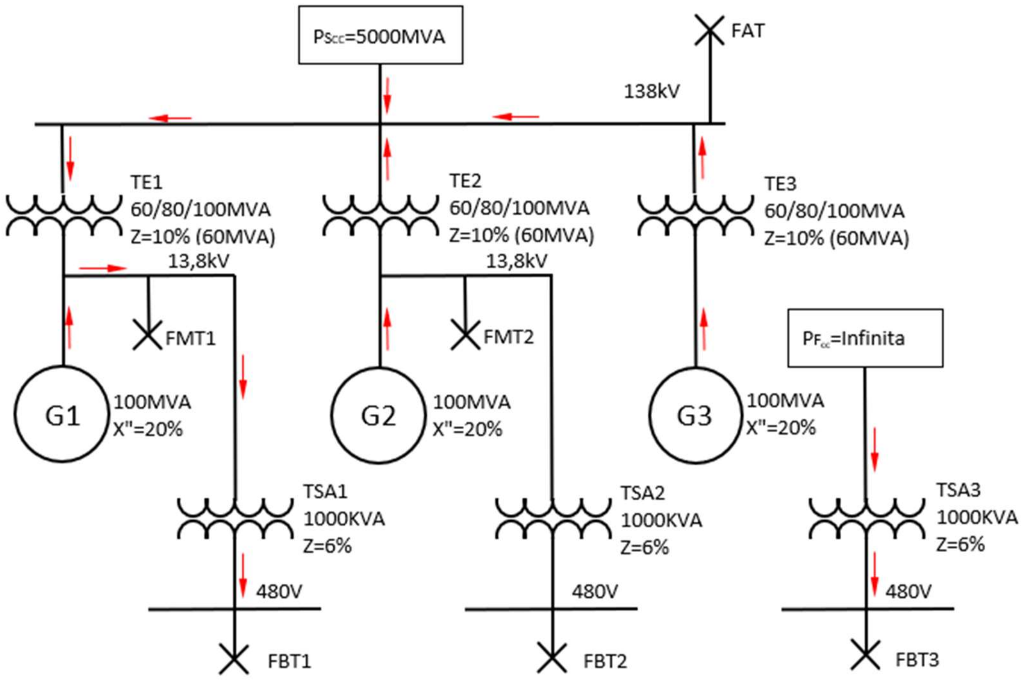

Considering that the maximum generation voltage can be +10%, the short circuit current for defining the symmetric short circuit current of the 13,8kV system should be increased by 10%, that is:

$$I_{FMT2} = 43,6x1,1 = 47,9kA$$

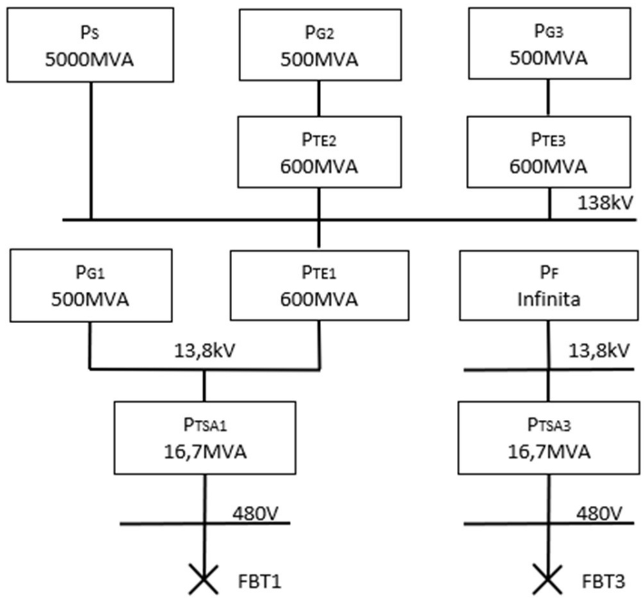
5.3.3 - 480V System

Calculation of Short Circuit Current in FBT1,2 and 3

For the 0.48kV system the system will be represented by the figure below:

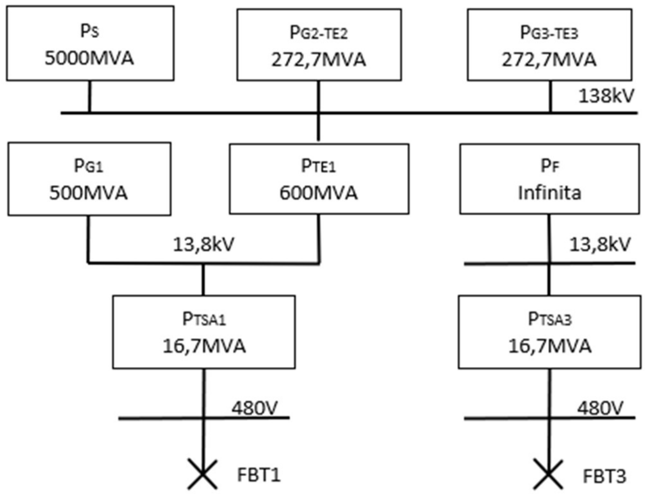


The block diagram below represents the system involved:

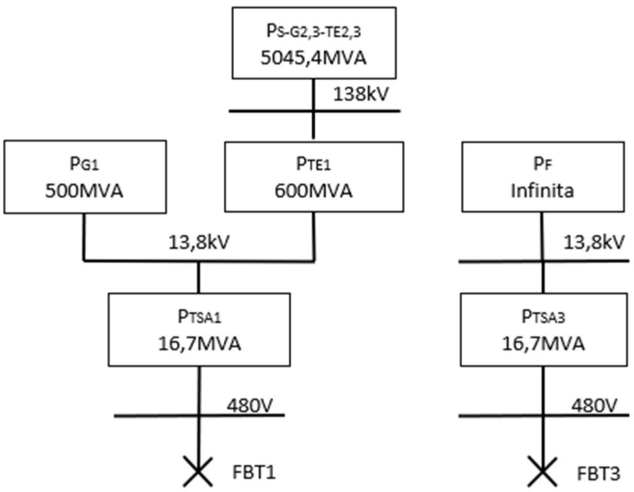



Calculating:

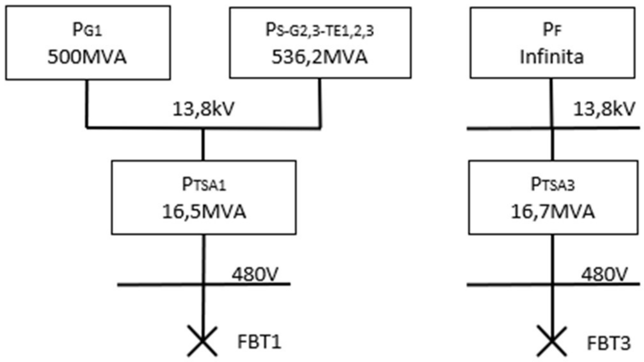
$$P_{G2-TE2} = \frac{1}{\frac{1}{P_{G2}} + \frac{1}{P_{TE2}}} = P_{G3-TE} = \frac{1}{\frac{1}{500} + \frac{1}{600}} = 272{,}7MVA$$



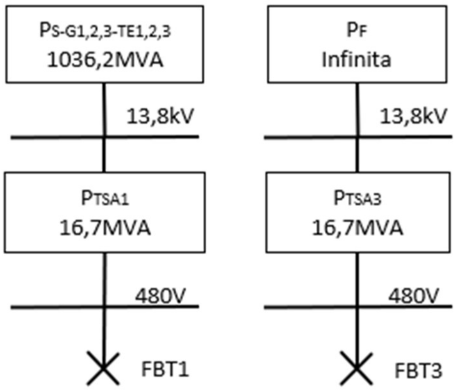

$$P_{S-G2,3-TE2,3} = P_S + P_{G2-TE} + P_{G3-TE3} = 5000 + 272{,}7 + 272{,}7 = 5045{,}4MVA$$




$$P_{S-G2,3-TE1,2,3} = \frac{1}{\frac{1}{P_{S-G2,3-TE2,3}} + \frac{1}{P_{TE1}}} = \frac{1}{\frac{1}{5045{,}4} + \frac{1}{600}} = 536{,}2MVA$$



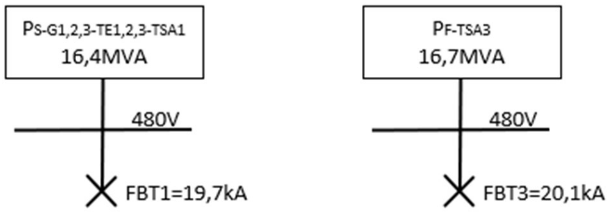

$$P_{S-G1,2,3-TE1,2,3} = P_{S-G2,3-TE1,2,3} + P_{G1} = 536{,}2 + 500 = 1036{,}2MVA$$




$$P_{S-G1,2,3-TE1,2,3} = \frac{1}{\frac{1}{P_{S-G1,2,3-TE1,2,3}} + \frac{1}{P_{TSA1}}} = \frac{1}{\frac{1}{1036{,}2} + \frac{1}{16{,}7}} = 16{,}4MVA$$

$$I_{FBT1} = \frac{16{,}4}{\sqrt{3}X0{,}48} = I_{FBT2} = 19{,}7kA$$

$$I_{FBT3} = \frac{16{,}7}{\sqrt{3}X0{,}48} = I_{FBT2} = 20{,}1kA$$




Considering that the maximum voltage of the 480V system can be +10%, the short circuit current for defining the symmetric short circuit current of the QG1 and QG2 tables, using the highest value, should be increased by 10%, that is:

$$I_{FBT} = 20{,}1x1{,}1 = 22{,}11kA$$

Attention is drawn to the small difference between the short circuit currents calculated for the 480V system, which most often justifies considering the short circuit power of the source as infinite.

5.3.4 - Conclusion

For medium and low voltage electrical auxiliary services, the short circuit currents should be, 50kA for the medium voltage system and 25kA for the low voltage switchboards, QG1 and QG2.

### 5.4 - Feeders

The definition of the feeders is a task that requires some care to meet all the requirements of the standards and needs of the installation.

In new projects, the conditions of installation of the cables and their paths cannot be clearly defined, which only occurs during the detailing of the installations. Thus, to size the cables correctly, care must be taken with the assumptions adopted, which often, even due to the recommendations of the manufacturers of the systems, lead to the oversizing of the cables.

Although the insulation of the cables withstands temperatures of 70ºC, 90ºC or 105ºC, which would cause serious damage if they encountered the human body, and there are hardly any facilities in which the cables cannot be touched, which demonstrates that, most of the time, we size the cables far above what would be necessary. This is because the most severe conditions, considered in the sizing of each circuit, do not occur continuously and the simultaneity of these conditions in the various circuits involved are not considered or verified. However, it is necessary to recognize that the prior definition of the conditions of installation of the cables is not an easy task to perform, especially to convince the customer of its applicability.

Whenever possible, cables with a higher operating temperature should be chosen, i.e., instead of choosing PVC insulated cables, choose EPR/XLPE insulated cables. The cost of copper cables is almost the same, but EPR/XLPE insulated cables withstand higher currents by approximately 30%, in addition to withstanding temperatures of 250ºC during short circuits.

The current conduction capacity of the cables depends on the cable material, type of insulation, ambient temperature, type of installation and grouping factor. However, these conditions will not be the subject of this informative, as the installation conditions are very varied and the standards detail all of them. The problem lies in the correct assessment of the real needs of the installation, definition of the active circuits and the grouping factors. What is observed is the oversizing of the cables due to the difficulties of predicting, at the beginning of the project, the conditions of installation of the cables at the end of the execution of the work, when it is no longer possible to change the section of the chosen cables. When the work is finished, one can only make a check of its correctness and, when necessary, make a more accurate calculation with the actual conditions.

Based on the load data, cables that simultaneously meet the capacity limits of current conduction, voltage drop, and short circuit should be chosen.

5.4.1 - Current Conduction Capability

For the choice of conductors by current conduction capacity, the following assumptions were arbitrated:

- Motor feeders are sized to 125% of the rated current, as recommended by the NEC (National Electrical Code). This recommendation is compatible with the conditions normally encountered because, as the power of asynchronous motors is considered constant, currents increase when voltages drop, and all motors usually have a service factor greater than 1.0.

- The feeders of the other loads were sized for 115% of the nominal current.

The ambient temperature correction factor considered the ambient temperature of 40ºC and the soil 25ºC.

To simplify the calculations, all cables inside the Powerhouse of the plant were considered installed in beds for cables, with a grouping factor equal to 0.7; the cables external to the Powerhouse were considered installed in conduits embedded in masonry, with a grouping factor equal to 0.8.

The current conduction capacities for EPR/XLPE insulated copper cables, already corrected for ambient temperature of 40ºC (Temperature Correction Factor=0.91), soil temperature 20ºC (Temperature Correction Factor =1.00), installed in the Powerhouse (Grouping

Correction Factor=0.8), or outside it (Grouping Correction Factor =0.9), are indicated in the following tables:

| Current carrying capacities (A) | | | | |
|---|---|---|---|---|
| Local | Powerhouse | | Other Locations | |
| Instalation | Cables tray | | Conduits | |
| Nominal Section | Three-core cables | Three single cables in trifoil | Three-core cables | Three single cables in trifoil |
| 2,5 | 23 | | 23 | |
| 4 | 31 | | 32 | |
| 6 | 39 | | 40 | |
| 10 | 55 | | 54 | |
| 16 | 73 | | 72 | |
| 25 | 92 | | 95 | |
| 35 | 115 | | 115 | |
| 50 | | 151 | | 158 |
| 70 | | 195 | | 200 |
| 95 | | 239 | | 242 |
| 120 | | 279 | | 281 |
| 150 | | 323 | | 322 |
| 185 | | 371 | | 367 |
| 240 | | 442 | | 433 |

The cable section, whose current conduction capacity is superior to the current that meets the load conditions, was chosen as the appropriate one to meet the current conduction capacity condition.

5.4.1.1. Auxiliary Service Transformers

The supply of the main loads' centers (QG1 and QG2) should be made with cables or buses sized for 115% of the nominal current of the auxiliary services transformer, that is:

$$I_{GE} = 1{,}15\frac{1000}{\sqrt{3}x0{,}48} = 1383A$$

If it is bus, the standardized rated current will be 1600A. If it is by cables, 4 cables should be used for phase, of 185mm$^2$, which support 1.484A.

5.4.1.2. Emergency Diesel Generator Set

The feeders of the main loads' centers, QG1 and QG2, coming from the emergency diesel generator set, were sized for 115% of the nominal current of the group, that is, for:

$$I_{GE} = 1{,}15\frac{360}{\sqrt{3}x0{,}48} = 498A$$

The minimum cable section that supports this current is 2 x 120mm$^2$ cables per phase, which support 558A.

The fact that the actual power of the alternator is 605kVA does not imply that the feeder should be sized for this power, since the nominal power of the group was 360kVA. The 605kVA alternator was chosen because it has the transient reactance equivalent to that required, and does not imply that the group is 605kVA, as the diesel engine must not necessarily meet the rated power of the actual alternator. However, due to all the variables involved, the plant operation personnel, knowing the real data of the equipment, will be able to take better advantage of the full capacity of the group.

The use of hybrid groups, with the actual information of the components, avoid the group supplier from placing a board in the alternator with the equivalent data instead of the real ones. For example, instead of informing that the alternator is 605kVA with transient reactance of 11.60%, reporting that the alternator is 360kVA with transient reactance of 6.90%, which is less than the calculated minimum required, 8.7%.

If we consider that the alternator can provide 110% of the rated power, for 1 hour every 12 hours of operation, the selected cables will still meet this condition, since the current supported by the two cables would be 558A (2 x 279A) higher than the 110% of the current of the 548A alternator (1.1 x 498A).

#### 5.4.1.3. Main Load's Centers

The data of the main loads' centers (QG1 and QG2), which feed all the load centers of the plant, considering the data of the estimated loads of the technical information IT.EL.SA. CA.02 Power Transformers and Emergency Generator Diesel Sets – Dimensioning, are listed in the following table:

| Load Center | l(m) | Total Load (kVA) | Load Current (A) | Minimum Cable Current (A) | Section ($m^2$) |
|---|---|---|---|---|---|
| CCU1 | 30 | 200 | 241 | 277 | **120** |
| CCU2 | 50 | 200 | 241 | 277 | **120** |
| CCU3 | 70 | 200 | 241 | 277 | **120** |
| CCG | 30 | 400 | 481 | 553 | **2x120** |
| CCTA | 80 | 55 | 66 | 76 | **25** |
| CCVT | 150 | 45 | 54 | 62 | **16** |
| CCSE | 150 | 30 | 36 | 41 | **10** |

#### 5.4.1.4. Load Centers

The sizing data, from the load centers that feed all the loads of the plant, are listed in the following tables:

| CCU LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) |
|---|---|---|---|---|---|---|---|
| Oil Pumps of Turbine's Speed Governor | 100 cv | MBORV | 35 | 124 | 1054 | 155 | **70** |
| Oil Circulation Pumps of Generator's Thrust and Guide Bearing | 10 cv | MBOMC | 25 | 14 | 112 | 17,5 | **2,5** |
| Oil Circulation Pumps of Turbine's Guide Bearing | 7,5 cv | MBOGT | 35 | 11 | 88 | 13,75 | **2,5** |
| Oil Injection Pumps of Thrust Bearing | 15 cv | MBIME | 25 | 21 | 168 | 26,25 | **4** |
| Turbine Cover Draining Pumps | 3 cv | MBDTT | 35 | 4,8 | 38,4 | 6 | **2,5** |
| Generator Heating Resistors | 15 kW | RAG | 25 | 18 | - | 20,7 | **2,5** |
| Turbine Well Oil Steam Exhauster | 0,5 cv | MEVT | 35 | 1,1 | 8,8 | 1,375 | **2,5** |
| Pumps or Valve of Unit Cooling Water System | 1,5 cv | MVAR | 35 | 3 | 24 | 3,75 | **2,5** |
| Generator Excitation Cubicle | 10 kVA | CEX | 25 | 12 | - | 13,8 | **2,5** |
| Auxiliaries of Step-Up Transformer | 30 kVA | ATE | 50 | 40 | 320 | 50 | **10** |
| Cooling Water System Self-Cleaning Filter | 1,5 cv | FALR | 35 | 3 | 24 | 3,75 | **2,5** |

| CCG LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) |
|---|---|---|---|---|---|---|---|
| Drainage Pumps | 20 cv | MBDE | 30 | 27 | 216 | 34 | **6** |
| Air Compressors of Speed Governor | 30 cv | MCARV | 30 | 40 | 320 | 50 | **10** |
| Ventilation and Exhaust System (1 Set) | 75 cv | MVE | 50 | 96 | Nota 1 | 120 | **50** |
| Air Conditioning System | 30 cv | SAC | 50 | 40 | 320 | 50 | **10** |
| Service Air Compressors | 15 cv | MCAS | 30 | 21 | 168 | 26 | **4** |
| Telecommunications System | 10 kVA | TELE | 50 | 12 | - | 14 | **2,5** |
| Battery Chargers | 15 kVA | CBT | 50 | 21 | - | 24 | **4** |
| Lighting and Heating Transformers | 10 kVA | TIACF | 80 | 12 | - | 14 | **2,5** |
| People Lift | 7,5 kVA | ELEV | 50 | 11 | 88 | 14 | **2,5** |
| Auxiliaries of the Diesel Emergency Generator Set | 1,5 kVA | AGDE | 40 | 2 | - | 2 | **2,5** |
| Rotor Lifting System Pump | 3 cv | BSLR | 80 | 4,8 | 38,4 | 6 | **2,5** |
| Depletion Pumps of Draft Tube | 30 cv | MBEG | 30 | 40 | 320 | 50 | **10** |
| Fire Fighting Pumps | 50 cv | MBI | 30 | 65 | 520 | 81 | **25** |
| Overhead Crane | 75 cv | PRCF | 50 | 96 | Nota 2 | 120 | **50** |
| Pow er Outlets | 30 kVA | TFCF | 80 | 36 | - | 41 | **10** |
| Mobile Insulating Oil Treatment System | 60 kVA | SMTOI | 80 | 72 | - | 83 | **25** |
| Mobile Lubricating Oil Treatment System | 30 kVA | SMTOL | 80 | 36 | 320 | 41 | **10** |
| Dow nstream Rolling Gantry | 15 kVA | PRJ | 50 | 18 | Nota 2 | 21 | **2,5** |

Note 1- The ventilation and exhaustion system is made up of a set of fans and exhausters of various pow ers, totaling 75hp.
Note 2- The crane and gantry crane are driven by a speed control system. Therefore, it has no inrush current.

| CCTA LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) |
|---|---|---|---|---|---|---|---|
| Lighting and Heating Transformers | 10 kVA | TIATA | 20 | 12 | - | 14 | **2,5** |
| Pow er Outlets | 30 kVA | TFTA | 80 | 36 | - | 41 | **10** |
| Upstream Rolling Gantry | 20 cv | PRTA | 50 | 27 | Nota 1 | 31 | **4** |
| Pumps of the Hydraulic Pow er Unit of the Water Intake Gates | 15 cv | MBCTA | 20 | 21 | 168 | 26 | **4** |

Note 1- The gantry crane is driven by a speed control system. Therefore, it has no inrush current.

| CCVT LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) |
|---|---|---|---|---|---|---|---|
| Lighting and Heating Transformers | 10 kVA | TIAVT | 20 | 12 | - | 14 | **2,5** |
| Pow er Outlets | 30 kVA | TFVT | 50 | 36 | - | 41 | **10** |
| Spillw ay Rolling Gantry | 15 cv | PRVT | 50 | 21 | Nota 1 | 24 | **4** |
| Pumps of the Hydraulic Pow er Unit of the Spillw ay Gates | 7,5 cv | MBCVT | 20 | 11 | 88 | 14 | **2,5** |

Note 1- The gantry crane is driven by a speed control system. Therefore, it has no inrush current.

| CCSE LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) |
|---|---|---|---|---|---|---|---|
| Lighting and Heating Transformers | 10 kVA | TIASE | 20 | 12 | - | 14 | **2,5** |
| Power Outlets | 30 kVA | TFSE | 50 | 36 | - | 41 | **10** |
| Motors of Switches and Circuit Breakers (1 Set) | 5cv | MDJCH | 80 | 7,6 | 60,8 | 10 | **2,5** |
| Note 1- It was considered that of the set of switch-disconnectors and circuit-breaker compressors, only one motor operates at a time. | | | | | | | |

5.4.2 - Voltage Drop

Using the spreadsheets of the reference documents can be calculated:

- The voltage in the load, when the value of the voltage at the source and the information of the loads and cables used are known. View spreadsheet PL.EL.SA.CA.04 - Feeders - Calculation of Voltage in Load.

- The voltage required at the source so that the voltage in the load is a predetermined value when the information of the loads and cables used is known. View spreadsheet PL.EL.SA.CA.05 - Feeders - Calculation of Voltage at Source.

The spreadsheets mentioned above were elaborated based on the theoretical information TE.EL.SA.CA.04 - Feeders - Calculation of Voltage and Load and Source.

5.4.2.1. Premises

For the choice of conductors by voltage drop, the following assumptions were arbitrated:

- For the load centers of the units (CCU1, CCU2 and CCU3) the voltage drops were calculated considering the start of the largest motor, 100hp, which is the oil pump motor of the turbine speed regulator.

- For the general load center (GCC) the voltage drop was calculated considering the start of the largest motor, 50hp, which is the fire pump motor.

- For the loads and load centers of the water intake (CCTA), spillway (CCVT) and Substation (CCSE) only the voltage drop in permanent regime was calculated.

The above assumptions were considered because the voltage in the terminals of the auxiliary service transformers for each load was not defined and, consequently, the voltage in the main loads' centers (QG1 and QG2). In this way, only the most critical circuits will be completely defined, and the others should be subject to a check, but will not be completely scaled in this informative.

The main loads' centers QG1 and QG2 are the center loads responsible for distributing the power to the plant's electrical auxiliary systems. As the distance from the auxiliary service transformers (TSA1, TSA2 and TSA3) to the main loads' centers (QG1 and QG2) are very short, the voltage drop in these connections will be disregarded. Therefore, the voltages in the QG1 and QG2 frames will be considered equal to the voltages in the terminals of the auxiliary service transformers, for the same load conditions.

Cable lengths were arbitrated considering the equipment arrangement defined at the beginning of this document.

As the chosen tap of the primary winding of the transformer corresponds to the nominal voltage, that is, 13,800V, the maximum voltage of the secondary of the transformers in empty will be 504V and in no case will the maximum voltage of the loads be exceeded. Therefore, only the behavior of those with the minimum and precarious voltages of the primary of the transformer will be the object of analysis.

The conditions of one or two transformers feeding all loads were considered.

Problems arising from low voltages should be expected and circumvented but should not be an impediment or reason to consider the facilities unviable. Note that, even in residential, commercial, and small business facilities, undervoltage problems can occur, because according to table 4 of ANEEL, voltages can vary in the same ranges as industrial systems:

**Tabela 4** – Pontos de conexão em Tensão Nominal igual ou inferior a 1 kV (220/127)

| Tensão de Atendimento (TA) | Faixa de Variação da Tensão de Leitura (Volts) |
|---|---|
| Adequada | (202≤TL≤231)/(117≤TL≤133) |
| Precária | (191≤TL<202 ou 231<TL≤233)/ (110≤TL<117 ou 133<TL≤135) |
| Crítica | (TL<191 ou TL>233)/(TL<110 ou TL>135) |

By the table, the appropriate voltage can vary between 92 and 105% of the rated voltage. The precarious voltage can reach 87% of the rated voltage, lower than the 90% of the 13,800V system.

5.4.2.2. Cable Resistance and Reactance

For EPR/XLPE insulated cables, the resistances and reactances in Ω/km will be as indicated in the following table, calculated according to the spreadsheet TE.EL.SA.CA.05 Feeders - Criteria for Dimensioning:

| *Cables Data* | | |
|---|---|---|
| ***S (mm²)*** | $R_{90}$ | $X_{60Hz}$ |
| **2,5** | 8,794 | 0,096 |
| **4** | 5,496 | 0,096 |
| **6** | 3,664 | 0,096 |
| **10** | 2,198 | 0,096 |
| **16** | 1,374 | 0,096 |
| **25** | 0,879 | 0,096 |
| **35** | 0,628 | 0,096 |
| **50** | 0,440 | 0,096 |
| **70** | 0,314 | 0,096 |
| **95** | 0,231 | 0,096 |
| **120** | 0,183 | 0,096 |
| **150** | 0,147 | 0,096 |
| **185** | 0,119 | 0,096 |
| **240** | 0,092 | 0,096 |

In this informative it was considered that the cables operate with the nominal temperature of 90ºC, that is, no simulations will be made considering the variations of the resistances as a function of the actual current of the load and capacity of the conductor at the nominal temperature. This simulation should only be done when the professional considers it necessary to make some critical evaluation of operation.

5.4.2.3. Quick Estimate

Before making the calculations to size the cables by the voltage drop, we will make a quick calculation to verify the approximate values of voltage that should be obtained in each stretch, simulating the values for the most severe condition that are the 100hp motors.

As the position of the load centers of the units (CCU1, CCU2 and CCU3), in relation to the loads, are the same, it will be calculated what will be the minimum voltage required at the source so that the voltage in the motor meets the minimum necessary value, considering the start of the motor of 100hp, with the cable section dimensioned by the criterion of current conduction, which is 70mm$^2$ cable.

So that, during the start of the 100hp motor, the minimum voltage at the motor terminals is 391V (460V, -15%), calculating the voltages at the sources with the aid of the spreadsheet PL.EL.SA.CA.05 (Feeders - Calculation of the Voltage at the Source) and using the data of the cables dimensioned by the criterion of current conduction, the voltage in the load centers of the units (CCU1/2/3), for feeder with 1 cable/phase of 70mm$^2$, should be ≥401,36V:

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Circuit Length (km) | 0,035 |
| | $Ra$ | Cable Resistance (Ω/km) | 0,314 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 1 |
| | $V_{C_T}$ | Voltage on the Load (V) | 391 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | |
| | $FP_{C_K}$ | Power Factor of the Constant Load | |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | |
| | $FP_{C_V}$ | Power Factor of the Variable Load | |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | 460 |
| | $I_{M_{Pn}}$ | Starting Current of the Motor(s) at Rated Voltage (A) | 1054 |
| | $FP_{M_P}$ | Fator de Potência do(s) Motor(es) na Partida | 0,3 |

| | | |
|---|---|---|
| $V_F$ | Source voltage considering the defined load voltage | 401,36 |

Adopting the same criteria for the fire pump, fed by the general load center (CCG), so that during the start of the 50hp motor, the minimum voltage at the motor terminals is 391V (460V, -15%), the voltage at the general load center (GCC) for feeder with 1 cable/phase of 25mm$^2$, should be ≥399.59V:

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Circuit Length (km) | 0,03 |
| | $Ra$ | Cable Resistance (Ω/km) | 0,879 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 1 |
| | $V_{C_T}$ | Voltage on the Load (V) | 391 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | |
| | $FP_{C_K}$ | Power Factor of the Constant Load | |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | |
| | $FP_{C_V}$ | Power Factor of the Variable Load | |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | 460 |
| | $I_{M_{Pn}}$ | Starting Current of the Motor(s) at Rated Voltage (A) | 520 |
| | $FP_{M_P}$ | Fator de Potência do(s) Motor(es) na Partida | 0,3 |

| | | |
|---|---|---|
| $V_F$ | Source voltage considering the defined load voltage | 399,59 |

For the voltage in CCU1 to be 401.36V, during the start of the 100hp motor, the voltage in QG1/QG2, for feeder with 1 cable/phase of 120mm², should be 409.87V:

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Circuit Length (km) | 0,03 |
| | $Ra$ | Cable Resistance (Ω/km) | 0,183 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 1 |
| | $V_{C_T}$ | Voltage on the Load (V) | 401,36 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 80 |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 460 |
| | $FP_{C_K}$ | Power Factor of the Constant Load | 0,85 |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | 20 |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | 480 |
| | $FP_{C_V}$ | Power Factor of the Variable Load | 0,9 |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | 460 |
| | $I_{M_{Pn}}$ | Starting Current of the Motor(s) at Rated Voltage (A) | 1054 |
| | $FP_{M_P}$ | Fator de Potência do(s) Motor(es) na Partida | 0,3 |

| | | |
|---|---|---|
| $V_F$ | Source voltage considering the defined load voltage | 409,87 |

The voltage drop, from the secondary terminals of the transformer to the motor terminals, will be 18.87V (409.87-391.00V), i.e., 4.10% of 460V, or 3.93% of 480V. Therefore, the estimated values are acceptable, given that the minimum voltage in the secondary transformer, during the start of the motor of 100hp, with the primary voltage at the minimum value of adequate voltage (12,834V), will be 409.33V, approximately equal to the estimated voltage.

For the voltage in the CCG to be 399.59V, during the start of the 50hp motor, the voltage in the QG1/QG2, for feeder with 2 cables/phase of 120mm², should be 403,78V:

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Circuit Length (km) | 0,03 |
| | $Ra$ | Cable Resistance (Ω/km) | 0,183 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 2 |
| | $V_{C_T}$ | Voltage on the Load (V) | 399,59 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 250 |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 460 |
| | $FP_{C_K}$ | Power Factor of the Constant Load | 0,85 |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | 100 |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | 480 |
| | $FP_{C_V}$ | Power Factor of the Variable Load | 0,9 |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | 460 |
| | $I_{M_{Pn}}$ | Starting Current of the Motor(s) at Rated Voltage (A) | 520 |
| | $FP_{M_P}$ | Fator de Potência do(s) Motor(es) na Partida | 0,3 |

| | | |
|---|---|---|
| $V_F$ | Source voltage considering the defined load voltage | 403,78 |

The calculations show that the situation is more critical for the load centers of the units.

Although the total voltage drop, during the start of the 100hp motor, is approximately equal to 4%, during the start of the 100hp motor, if the primary voltage of the transformer is in the value of the precarious range (<93% of the nominal voltage), it will not be possible to meet the minimum voltage values defined in this technical information.

The fact that it is not possible to meet, theoretically, the minimum values of voltage in the equipment, does not imply the problems of this undervoltage will prevent its operation. However, any operating problems can be circumvented with the adoption of some measures, such as the use of contactors driven with direct current, soft starters, etc., or other measures, by the operation personnel, such as changing the tap of the transformer primary winding.

Depending on the calculated values, measures such as increasing and nominal power of the transformers and the section of the feeders, may reduce the problems of the minimum voltage values, but must be subject to a technical and economic evaluation, as well as have the approval of the Customer.

5.4.2.4. Emergency Diesel Generator Set

Considering the planned arrangement for the powerhouse, the length of the cable, between the emergency diesel generator set and the main load's centers QG1/QG2, will be estimated at 30m. Therefore, the voltage drops in the feeders, considering the same loads of the calculation of the voltage drop in the emergency diesel generator set, will be:

In the first condition, the group feeds a constant initial load of 260kVA (rated voltage 460V, power factor 0.85) and variable load of 50kVA (rated voltage 480V, power factor 0.90), and motor start of 50hp.

Before starting the motor, the voltage in QG1 and QG2, assuming the voltage in the alternator set at 506V and a single feeder of 2x120mm$^2$ per phase for the two frames, will be 504.07V.

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,03 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,183 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 2 |
| | $V_F$ | Source Voltage (V) | 506 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 260 |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 460 |
| | $FP_{C_K}$ | Power Factor of the Constant Load | 0,85 |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | 50 |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | 480 |
| | $FP_{C_V}$ | Power Factor of the Variable Load | 0,9 |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | |
| | $I_{M_{Pn}}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FP_{M_P}$ | Power Factor of the Motor(s) at Starting | |

| | | |
|---|---|---|
| $V_{C_T}$ | *Load voltage considering the defined source voltage* | 504,07 |

During the start of the 50hp motor, with the above considered load, the voltage at the terminals of the alternator of the diesel group will be 465.91V.

| 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) | 605 |
| Alternator | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 11,6 |
| Loads Data – Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 260 |
| 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) | 520 |
| Loads Data – Load to be Applied | $FPM_P$ | Power Factor of Motor(s) at Starting | 0,3 |

| | | |
|---|---|---|
| *Voltage at the Alternator Terminals (V)* | $V_{GT}$ (%) | **465,91** |

And the voltage on QG1 and QG2 will be 461.87V.

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,03 |
| Source Data | $Ra$ | Cable Resistence (Ω/km) | 0,183 |
| Source Data | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| Source Data | $n$ | Number of Cables per Phase | 2 |
| Source Data | $V_F$ | Source Voltage (V) | 465,91 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 260 |
| Cargo Data | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 460 |
| Cargo Data | $FP_{C_K}$ | Power Factor of the Constant Load | 0,85 |
| Cargo Data | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | 50 |
| Cargo Data | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | 480 |
| Cargo Data | $FP_{C_V}$ | Power Factor of the Variable Load | 0,9 |
| Cargo Data | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | 460 |
| Cargo Data | $I_{M_{Pn}}$ | Starting Current of Motor(s) at Rated Voltage (A) | 520 |
| Cargo Data | $FP_{M_P}$ | Power Factor of the Motor(s) at Starting | 0,3 |

| | | |
|---|---|---|
| $V_{C_T}$ | *Load voltage considering the defined source voltage* | 461,87 |

After starting the 50hp motor, the constant load will go from 260kVA to 310kVA and, with the voltage in the alternator stabilizes at 506V, the voltage in QG1 and QG2, considering the feeders of 2 cables of 120mm2 per phase, will be 503.76V.

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,03 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,183 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 2 |
| | $V_F$ | Source Voltage (V) | 506 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 310 |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 460 |
| | $FP_{C_K}$ | Power Factor of the Constant Load | 0,85 |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | 50 |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | 480 |
| | $FP_{C_V}$ | Power Factor of the Variable Load | 0,9 |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | |
| | $I_{M_{Pn}}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FP_{M_P}$ | Power Factor of the Motor(s) at Starting | |

| | | |
|---|---|---|
| $V_{C_T}$ | *Load voltage considering the defined source voltage* | 503,76 |

In the second condition, the group feeds a constant initial load of 210kVA (rated voltage 460V, power factor 0.85) and variable load of 50kVA (rated voltage 480V, power factor 0.90), and engine start of 100hp.

Before starting the motor, the voltage in QG1 and QG2, will be 504.37V.

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,03 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,183 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 2 |
| | $V_F$ | Source Voltage (V) | 506 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 210 |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 460 |
| | $FP_{C_K}$ | Power Factor of the Constant Load | 0,85 |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | 50 |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | 480 |
| | $FP_{C_V}$ | Power Factor of the Variable Load | 0,9 |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | |
| | $I_{M_{Pn}}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FP_{M_P}$ | Power Factor of the Motor(s) at Starting | |

| | | |
|---|---|---|
| $V_{C_T}$ | *Load voltage considering the defined source voltage* | 504,37 |

During the start of the 100hp motor, with the initial load above, the voltage at the terminals of the alternator of the diesel group will be 431.00V.

| 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) | 605 |
| | | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 11,6 |
| 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 |

| | | |
|---|---|---|
| *Voltage at the Alternator Terminals (V)* | $V_{GT}$ (%) | **431,00** |

The voltage in QG1 and QG2, for the voltage of 431.00V in the alternator terminals, will be 425.46V.

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,03 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,183 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 2 |
| | $V_F$ | Source Voltage (V) | 431 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 210 |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 460 |
| | $FP_{C_K}$ | Power Factor of the Constant Load | 0,85 |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | 50 |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | 480 |
| | $FP_{C_V}$ | Power Factor of the Variable Load | 0,9 |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | 460 |
| | $I_{M_{Pn}}$ | Starting Current of Motor(s) at Rated Voltage (A) | 1054 |
| | $FP_{M_P}$ | Power Factor of the Motor(s) at Starting | 0,3 |

| | | |
|---|---|---|
| $V_{C_T}$ | *Load voltage considering the defined source voltage* | 425,46 |

After starting the 100hp motor, the constant load will go from 210kVA to 310kVA and the voltage in QG1 and QG2 will be 503.76V:

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,03 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,183 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 2 |
| | $V_F$ | Source Voltage (V) | 506 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 310 |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 460 |
| | $FP_{C_K}$ | Power Factor of the Constant Load | 0,85 |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | 50 |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | 480 |
| | $FP_{C_V}$ | Power Factor of the Variable Load | 0,9 |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | |
| | $I_{M_{Pn}}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FP_{M_P}$ | Power Factor of the Motor(s) at Starting | |

| | | |
|---|---|---|
| $V_{C_T}$ | *Load voltage considering the defined source voltage* | 503,76 |

The above conditions are summarized in the following table:

| Voltages at QG1 and QG2 - Source: Diesel Emergency Set | | | | |
|---|---|---|---|---|
| Loads | | | | |
| Initial | | +Start of | Final | |
| Constant (kVA) | Variable (kVA) | Motor (cv) | Constant (kVA) | Variable (kVA) |
| 260,00 | 50,00 | 50 | 310,00 | 50,00 |
| 504,07 | | 461,87 | 503,76 | |
| 210,00 | 50,00 | 100 | | |
| 504,37 | | 431,00 | | |

As the voltages in the QG1 and QG2 will be the same as that of the secondary of the TSA1, TSA2 or TSA3 transformers, and the voltages in the main load's centers, when fed by the diesel group, during the start of the 50hp and 100hp motors will be 461.87V and 431.00V, respectively, and are higher than the transformer voltages (419.47/427.83V and 409.29/417.57V), when the voltage in the primary is 12,834V, The analysis of the behavior of the loads by the voltage drop when fed by the diesel group will not be made.

5.4.2.5. Centers Loads

With the choice of the derivation of the primary winding (tap 13800V), the maximum possible voltage in the secondary will be 504V. Therefore, since there will be no overvoltage problem, the calculations of the voltage drops will consider only the lowest voltage values in the primary of the transformers.

When the voltage drops, calculated with the values of resistance and reactance of the cables and according to the criteria of current conduction capacity, have not been as expected, the sections of the cables were increased to improve the values. The changed sections are highlighted in blue.

The calculations were made with the aid of the spreadsheet PE.EL.SA.CA.04 (Feeders - Calculation of Voltage in Load).

In the calculations of the voltages of the load centers of the units (CCU's), the voltage in the main loads' centers (QG1/QG2) was considered with the 100hp motor starting; in the calculations of the voltage in the general loads center (GCC), the voltage in the main loads' centers (QG1/QG2) was considered with the 50hp engine motor.

For the calculations of the voltages in the load centers of the water intake (CCTA), spillway (CCVT) and substation (CCSE), only the voltage in permanent regime was calculated.

The voltage value 429.94V in the main loads' centers (QG1/QG2), corresponds to the value of the voltage in the secondary of the transformer, when the voltage in the primary is 12,834V, for the maximum load of the plant, that is, a constant load of 650kVA and a variable load of 150kVA.

The voltage value 415.09V, in the main loads' centers (QG1/QG2), corresponds to the value of the voltage in the secondary of the transformer, when the voltage in the primary is 12,420V, for the maximum load of the plant, that is, a constant load of 650kVA and a variable load of 150kVA.

The feeder's sections of the CCTA, CCVT and CCSE has been increased to keep the stresses in these load centers at values approximately equal to those of the powerhouse load centers.

In the following tables are indicated the data and results of the calculations of voltage drops, from the main loads' centers, QG1/QG2, to the others load centers, considering one or two transformers feeding the entire load of the plant, with voltage in the primary with 12,834V and 12,420V.

With one transformer feeding the entire load, with 12.834V in the primary:

| *Values for Transformer Primary Voltage 12.834V* | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Load Center* | *l(m)* | *Section ($mm^2$)* | *Constant Load (kVA)* | *Variable Load (kVA)* | *Biggest Motor (cv)* | *QG Voltage* | *CC Voltage (V)* |
| ***CCU1*** | 30 | **150** | 80 | 20 | | 432,22 | **431,05** |
| | | | 80 | 20 | 100 | 409,29 | **401,54** |
| | | | 180 | 20 | | 429,94 | **427,53** |
| ***CCU2*** | 50 | **2x95** | 80 | 20 | | 432,22 | **430,84** |
| | | | 80 | 20 | 100 | 409,29 | **401,36** |
| | | | 180 | 20 | | 429,94 | **427,11** |
| ***CCU3*** | 70 | **2x240** | 80 | 20 | | 432,22 | **431,22** |
| | | | 80 | 20 | 100 | 409,29 | **401,58** |
| | | | 180 | 20 | | 429,94 | **427,88** |
| ***CCG*** | 30 | **2x120** | 250 | 100 | | 432,22 | **429,84** |
| | | | 250 | 100 | 50 | 409,29 | **405,09** |
| | | | 300 | 100 | | 429,94 | **427,19** |
| ***CCTA*** | 80 | **95** | 20 | 20 | | Note | **Note** |
| | | | 20 | 20 | 15 | Note | **Note** |
| | | | 35 | 20 | | 429,94 | **427,58** |
| ***CCVT*** | 150 | **120** | 17,5 | 20 | | Note | **Note** |
| | | | 17,5 | 20 | 7,5 | Note | **Note** |
| | | | 25 | 20 | | 429,94 | **426,98** |
| ***CCSE*** | 150 | **70** | 5 | 20 | | Note | **Note** |
| | | | 5 | 20 | 5 | Note | **Note** |
| | | | 10 | 20 | | 429,94 | **427,02** |
| Note: Uncalculated values | | | | | | | |

With two transformers feeding the entire load and 12,834V in the primary:

| Values for Transformer Primary Voltage 12.834V | | | | | | | |
|---|---|---|---|---|---|---|---|
| Load Center | l(m) | Section (mm²) | Constant Load (kVA) | Variable Load (kVA) | Biggest Motor (cv) | QG Voltage | CC Voltage (V) |
| CCU1 | 30 | 150 | 80 | 20 | | 440,53 | 439,37 |
| | | | 80 | 20 | 100 | 417,57 | 409,70 |
| | | | 180 | 20 | | 438,38 | 436,01 |
| CCU2 | 50 | 2x95 | 80 | 20 | | 440,53 | 439,17 |
| | | | 80 | 20 | 100 | 417,57 | 409,53 |
| | | | 180 | 20 | | 438,38 | 435,59 |
| CCU3 | 70 | 2x240 | 80 | 20 | | 440,53 | 439,54 |
| | | | 80 | 20 | 100 | 417,57 | 409,74 |
| | | | 180 | 20 | | 438,38 | 436,36 |
| CCG | 30 | 2x120 | 250 | 100 | | 440,53 | 438,18 |
| | | | 250 | 100 | 50 | 417,57 | 413,36 |
| | | | 300 | 100 | | 438,38 | 435,67 |
| CCTA | 80 | 95 | 20 | 20 | | Note | Note |
| | | | 20 | 20 | 15 | Note | Note |
| | | | 35 | 20 | | 438,38 | 436,04 |
| CCVT | 150 | 120 | 17,5 | 20 | | Note | Note |
| | | | 17,5 | 20 | 7,5 | Note | Note |
| | | | 25 | 20 | | 438,38 | 435,43 |
| CCSE | 150 | 70 | 5 | 20 | | Note | Note |
| | | | 5 | 20 | 5 | Note | Note |
| | | | 10 | 20 | | 438,38 | 435,45 |
| Note: Uncalculated values | | | | | | | |

With one transformer feeding the entire load and 12,420V in the primary:

| Values for Transformer Primary Voltage12.420V | | | | | | | |
|---|---|---|---|---|---|---|---|
| Load Center | l(m) | Section (mm²) | Constant Load (kVA) | Variable Load (kVA) | Biggest Motor (cv) | QG Voltage | CC Voltage (V) |
| CCU1 | 30 | 150 | 80 | 20 | | 417,46 | 416,26 |
| | | | 80 | 20 | 100 | 395,26 | 387,70 |
| | | | 180 | 20 | | 415,09 | 412,61 |
| CCU2 | 50 | 2x95 | 80 | 20 | | 417,46 | 416,05 |
| | | | 80 | 20 | 100 | 395,26 | 387,52 |
| | | | 180 | 20 | | 415,09 | 412,17 |
| CCU3 | 70 | 2x240 | 80 | 20 | | 417,46 | 416,44 |
| | | | 80 | 20 | 100 | 395,26 | 387,75 |
| | | | 180 | 20 | | 415,09 | 412,97 |
| CCG | 30 | 2x120 | 250 | 100 | | 417,46 | 415,04 |
| | | | 250 | 100 | 50 | 395,26 | 391,07 |
| | | | 300 | 100 | | 415,09 | 412,29 |
| CCTA | 80 | 95 | 20 | 20 | | Note | Note |
| | | | 20 | 20 | 15 | Note | Note |
| | | | 35 | 20 | | 415,09 | 412,75 |
| CCVT | 150 | 120 | 17,5 | 20 | | Note | Note |
| | | | 17,5 | 20 | 7,5 | Note | Note |
| | | | 25 | 20 | | 415,09 | 413,11 |
| CCSE | 150 | 70 | 5 | 20 | | Note | Note |
| | | | 5 | 20 | 5 | Note | Note |
| | | | 10 | 20 | | 415,09 | 412,19 |
| Note: Uncalculated values | | | | | | | |

With two transformers feeding the entire load and 12,420V on the primary:

| Values for Transformer Primary Voltage12.420V | | | | | | | |
|---|---|---|---|---|---|---|---|
| Load Center | l(m) | Section ($mm^2$) | Constant Load (kVA) | Variable Load (kVA) | Biggest Motor (cv) | QG Voltage | CC Voltage (V) |
| CCU1 | 30 | 150 | 80 | 20 | | 426,00 | **424,82** |
| | | | 80 | 20 | 100 | 403,79 | **396,11** |
| | | | 180 | 20 | | 423,78 | **421,34** |
| CCU2 | 50 | 2x95 | 80 | 20 | | 426,00 | **424,61** |
| | | | 80 | 20 | 100 | 403,79 | **395,93** |
| | | | 180 | 20 | | 423,78 | **420,91** |
| CCU3 | 70 | 2x240 | 80 | 20 | | 426,00 | **424,99** |
| | | | 80 | 20 | 100 | 403,79 | **396,16** |
| | | | 180 | 20 | | 423,78 | **421,70** |
| CCG | 30 | 2x120 | 250 | 100 | | 426,00 | **423,91** |
| | | | 250 | 100 | 50 | 403,79 | **399,60** |
| | | | 300 | 100 | | 423,78 | **421,01** |
| CCTA | 80 | 95 | 20 | 20 | | Note | **Note** |
| | | | 20 | 20 | 15 | Note | **Note** |
| | | | 35 | 20 | | 423,78 | **421,41** |
| CCVT | 150 | 120 | 17,5 | 20 | | Note | **Note** |
| | | | 17,5 | 20 | 7,5 | Note | **Note** |
| | | | 25 | 20 | | 423,80 | **420,83** |
| CCSE | 150 | 70 | 5 | 20 | | Note | **Note** |
| | | | 5 | 20 | 5 | Note | **Note** |
| | | | 10 | 20 | | 423,78 | **420,87** |
| Note: Uncalculated values | | | | | | | |

Note: The values of the voltages in the CCTA, CCVT and CCSE load centers were only calculated for the permanent operating regime because the corresponding calculations of voltage drop in the transformers were not made for the load conditions that should be considered. However, as the voltage values for the permanent regime are practically the same as the load centers of the powerhouse, which have the heaviest loads, no problems should be found.

5.4.2.6. Load Centers

As in the general tables, depending on the choice of the tap of the primary winding (tap 13800V), the maximum possible voltage in the secondary will be 504V. Therefore, the calculation of voltage drops considered only the lowest voltage values in the main loads centers (QG1/QG2), which occurs for the primary voltages of 12,834V and 12,420V, with a single transformer feeding the entire load of the installation.

When the voltage drops calculated with the values of resistance and reactance of the cables, calculated according to the criteria of current conduction capacity were not as expected, the sections of the cables were increased to improve the values. The changed sections are highlighted in blue.

The calculations were made with the aid of the spreadsheet PE.EL.SA.CA.04 (Feeders - Calculation of Voltage in Load). For the calculations of the voltages in the loads, it was considered that 1hp=1cv=1kVA with a power factor of 0.85 for all loads, except for the heating resistors of the generators, where it was considered a power factor equal to 1.

In the calculations of the voltages of the load centers of the units (CCU's), the voltage in the main load's centers (QG1/QG2) was considered with the 100hp motor starting and, in the calculations of the voltage in the general center loads (CCG), the voltage in the main load's centers (QG1/QG2) was considered with the 50hp motor starting.

For the calculations of the voltages in the load centers of the water intake (CCTA), spillway (CCVT) and substation (CCSE), only the voltage in permanent regime was calculated.

The values of voltages in the centers of loads (CC), for the alternatives considered, were obtained from the calculations already made for the general tables.

In the following tables are indicated the data and results of the calculations of the voltage drops, from the load centers to the loads, considering one or two transformers feeding the entire load of the plant.

With one transformer feeding the entire load and 12.834V in the primary:

| Values for Transformer Primary Voltage 12.834V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCU's LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCU2 | Carga |
| Oil Pumps of Turbine's Speed Governor | 100 cv | MBORV | 35 | 124 | 1054 | 155 | 70 | 401,36 | 391,00 |
| | | | | | | | | 427,11 | 424,49 |
| Oil Circulation Pumps of Generator's Thrust and Guide Bearing | 10 cv | MBOMC | 25 | 14 | 112 | 17,5 | 4 | Note 1 | Note 1 |
| | | | | | | | | 427,11 | 424,32 |
| Oil Circulation Pumps of Turbine's Guide Bearing | 7,5 cv | MBOGT | 35 | 11 | 88 | 13,75 | 4 | Note 1 | Note 1 |
| | | | | | | | | 427,11 | 424,18 |
| Oil Injection Pumps of Thrust Bearing | 15 cv | MBIME | 25 | 21 | 168 | 26,25 | 6 | Note 1 | Note 1 |
| | | | | | | | | 427,11 | 424,31 |
| Turbine Cover Draining Pumps | 3 cv | MBDTT | 35 | 4,8 | 38,4 | 6 | 2,5 | Note 1 | Note 1 |
| | | | | | | | | 427,11 | 424,94 |
| Generator Heating Resistors | 15 kW | RAG | 25 | 18 | - | 20,7 | 6 | 427,11 | 424,58 |
| Turbine Well Oil Steam Exhauster | 0,5 cv | MEVT | 35 | 1,1 | 8,8 | 1,375 | 2,5 | Note 1 | Note 1 |
| | | | | | | | | 427,11 | 426,80 |
| Pumps or Valve of Unit Cooling Water System | 1,5 cv | MVAR | 35 | 3 | 24 | 3,75 | 2,5 | Note 1 | Note 1 |
| | | | | | | | | 427,11 | 426,18 |
| Generator Excitation Cubicle | 10 kVA | CEX | 25 | 12 | - | 13,8 | 4 | Note 1 | Note 1 |
| | | | | | | | | 427,11 | 424,32 |
| Auxiliaries of Step-Up Transformer | 30 kVA | ATE | 50 | 40 | 320 | 50 | 25 | 427,11 | 424,29 |
| Cooling Water System Self-Cleaning Filter | 1,5 cv | FALR | 35 | 3 | 24 | 3,75 | 2,5 | Note 1 | Note 1 |
| | | | | | | | | 427,11 | 426,18 |
| Note 1 - Uncalculated values. | | | | | | | | | |

| Values for Transformer Primary Voltage 12.834V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCG'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCG | Carga |
| Drainage Pumps | 20 cv | MBDE | 30 | 27 | 216 | 34 | 6 | Note 3 | Note 3 |
| | | | | | | | | 427,19 | 422,69 |
| Air Compressors of Speed Governor | 30 cv | MCARV | 30 | 40 | 320 | 50 | 10 | Note 3 | Note 3 |
| | | | | | | | | 427,19 | 423,10 |
| Ventilation and Exhaust System (1 Set) | 75 cv | MVE | 50 | 96 | Note 1 | 120 | 50 | 427,19 | 423,43 |
| Air Conditioning System | 30 cv | SAC | 50 | 40 | 320 | 50 | 10 | Note 3 | Note 3 |
| | | | | | | | | 427,19 | 420,32 |
| Service Air Compressors | 15 cv | MCAS | 30 | 21 | 168 | 26 | 4 | Note 3 | Note 3 |
| | | | | | | | | 427,19 | 422,15 |
| Telecommunications System | 10 kVA | TELE | 50 | 12 | - | 14 | 6 | 427,19 | 423,45 |
| Battery Chargers | 15 kVA | CBT | 50 | 21 | - | 24 | 10 | 427,19 | 423,79 |
| Lighting and Heating Transformers | 10 kVA | TIACF | 80 | 12 | - | 14 | 10 | 427,19 | 423,56 |
| People Lift | 7,5 kVA | ELEV | 50 | 11 | 88 | 14 | 4 | Note 3 | Note 3 |
| | | | | | | | | 427,19 | 423,00 |
| Auxiliaries of the Diesel Emergency Generator Set | 1,5 kVA | AGDE | 40 | 2 | - | 2 | 2,5 | 427,19 | 426,13 |
| Note 1- The ventilation and exhaustion system consists of a set of fans and exhausters, totaling 75hp.<br>Note 2- The crane and gantry crane are driven by a speed control system. Therefore, it has no inrush current..<br>Note 3- Uncalculated values. | | | | | | | | | |

| Values for Transformer Primary Voltage 12.834V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCG'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCG | Carga |
| Rotor Lifting System Pump | 3 cv | BSLR | 80 | 4,8 | 38,4 | 6 | **2,5** | Note 3<br>**427,19** | Note 3<br>**422,91** |
| Depletion Pumps of Draft Tube | 30 cv | MBEG | 30 | 40 | 320 | 50 | **10** | Note 3<br>**427,19** | Note 3<br>**423,10** |
| Fire Fighting Pumps | 50 cv | MBI | 30 | 65 | 520 | 81 | **25** | **405,09**<br>**427,19** | **396,38**<br>**424,37** |
| Overhead Crane | 75 cv | PRCF | 50 | 96 | Note 2 | 120 | **50** | **427,19** | **423,43** |
| Pow er Outlets | 30 kVA | TFCF | 80 | 36 | - | 41 | **25** | **427,19** | **422,65** |
| Mobile Insulating Oil Treatment System | 60 kVA | SMTOI | 80 | 72 | - | 83 | **50** | **427,19** | **422,36** |
| Mobile Lubricating Oil Treatment System | 30 kVA | SMTOL | 80 | 36 | - | 41 | **25** | **427,19** | **422,65** |
| Dow nstream Rolling Gantry | 15 kVA | PRJ | 50 | 18 | Note 2 | 21 | **10** | **427,19** | **423,79** |

Note 1- The ventilation and exhaustion system consists of a set of fans and exhausters, totaling 75hp.
Note 2- The crane and gantry crane are driven by a speed control system. Therefore, it has no inrush current..
Note 3- Uncalculated values.

| Values for Transformer Primary Voltage 12.834V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCTA'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCTA | Carga |
| Lighting and Heating Transformers | 10 kVA | TIATA | 20 | 12 | - | 14 | **4** | **427,58** | **425,36** |
| Pow er Outlets | 30 kVA | TFTA | 80 | 36 | - | 41 | **25** | **427,58** | **398,83** |
| Upstream Rolling Gantry | 20 cv | PRTA | 50 | 27 | Note 1 | 31 | **10** | **427,58** | **423,04** |
| Pumps of the Hydraulic Pow er Unit of the Water Intake Gates | 15 cv | MBCTA | 20 | 21 | 168 | 26 | **4** | Note 2<br>**427,58** | Note 2<br>**424,24** |

Note 1- The gantry crane is driven by a speed control system. Therefore, it has no inrush current.
Note 2- Uncalculated values

| Values for Transformer Primary Voltage 12.834V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCVT'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCTV | Carga |
| Lighting and Heating Transformers | 10 kVA | TIAVT | 20 | 12 | - | 14 | **4** | **426,98** | **424,75** |
| Pow er Outlets | 30 kVA | TFVT | 50 | 36 | - | 41 | **25** | **426,98** | **424,16** |
| Spillw ay Rolling Gantry | 15 cv | PRVT | 50 | 21 | Note 1 | 24 | **10** | **426,98** | **423,58** |
| Pumps of the Hydraulic Pow er Unit of the Spillw ay Gates | 7,5 cv | MBCVT | 20 | 11 | 88 | 14 | **2,5** | Note 2<br>**426,98** | Note 2<br>**424,32** |

Note 1- The gantry crane is driven by a speed control system. Therefore, it has no inrush current.
Note 2- Uncalculated values

| Values for Transformer Primary Voltage 12.834V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCSE'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCSE | Carga |
| Lighting and Heating Transformers | 10 kVA | TIASE | 20 | 12 | - | 14 | **6** | **427,07** | **425,58** |
| Pow er Outlets | 30 kVA | TFSE | 50 | 36 | - | 41 | **25** | **427,02** | **424,25** |
| Motors of Sw itches and Circuit Breakers (1 Set) | 5cv | MDJCH | 80 | 7,6 | 60,8 | 10 | **6** | Note 1<br>**427,07** | Note 1<br>**424,08** |

Note 1- Uncalculated values
Note 2- It w as considered that of the set of sw itch-disconnectors and circuit-breaker compressors, only one motor operates at a time.

With two transformers feeding the entire load and 12,834V in the primary:

| Values for Transformer Primary Voltage 12.834V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCU's LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
| | | | | | | | | CCU2 | Carga |
| Oil Pumps of Turbine's Speed Governor | 100 cv | MBORV | 35 | 124 | 1054 | 155 | 70 | 409,53<br>435,59 | 398,96<br>433,02 |
| Oil Circulation Pumps of Generator's Thrust and Guide Bearing | 10 cv | MBOMC | 25 | 14 | 112 | 17,5 | 4 | Note 1<br>435,59 | Note 1<br>432,86 |
| Oil Circulation Pumps of Turbine's Guide Bearing | 7,5 cv | MBOGT | 35 | 11 | 88 | 13,75 | 4 | Note 1<br>435,59 | Note 1<br>432,72 |
| Oil Injection Pumps of Thrust Bearing | 15 cv | MBIME | 25 | 21 | 168 | 26,25 | 6 | Note 1<br>435,59 | Note 1<br>432,85 |
| Turbine Cover Draining Pumps | 3 cv | MBDTT | 35 | 4,8 | 38,4 | 6 | 2,5 | Note 1<br>435,59 | Note 1<br>433,46 |
| Generator Heating Resistors | 15 kW | RAG | 25 | 18 | - | 20,7 | 6 | 435,59 | 433,01 |
| Turbine Well Oil Steam Exhauster | 0,5 cv | MEVT | 35 | 1,1 | 8,8 | 1,375 | 2,5 | Note 1<br>435,59 | Note 1<br>435,29 |
| Pumps or Valve of Unit Cooling Water System | 1,5 cv | MVAR | 35 | 3 | 24 | 3,75 | 2,5 | Note 1<br>435,59 | Note 1<br>434,68 |
| Generator Excitation Cubicle | 10 kVA | CEX | 25 | 12 | - | 13,8 | 4 | Note 1<br>435,59 | Note 1<br>432,86 |
| Auxiliaries of Step-Up Transformer | 30 kVA | ATE | 50 | 40 | 320 | 50 | 25 | 435,59 | 432,82 |
| Cooling Water System Self-Cleaning Filter | 1,5 cv | FALR | 35 | 3 | 24 | 3,75 | 2,5 | Note 1<br>435,59 | Note 1<br>434,68 |

Note 1 - Uncalculated values.

| Values for Transformer Primary Voltage 12.834V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCG'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
| | | | | | | | | CCG | Carga |
| Drainage Pumps | 20 cv | MBDE | 30 | 27 | 216 | 34 | 6 | Note 3<br>435,67 | Note 3<br>431,26 |
| Air Compressors of Speed Governor | 30 cv | MCARV | 30 | 40 | 320 | 50 | 10 | Note 3<br>435,67 | Note 3<br>431,66 |
| Ventilation and Exhaust System (1 Set) | 75 cv | MVE | 50 | 96 | Note 1 | 120 | 50 | 435,67 | 431,98 |
| Air Conditioning System | 30 cv | SAC | 50 | 40 | 320 | 50 | 10 | Note 3<br>435,67 | Note 3<br>428,94 |
| Service Air Compressors | 15 cv | MCAS | 30 | 21 | 168 | 26 | 4 | Note 3<br>435,67 | Note 3<br>430,73 |
| Telecommunications System | 10 kVA | TELE | 50 | 12 | - | 14 | 6 | 435,67 | 432,00 |
| Battery Chargers | 15 kVA | CBT | 50 | 21 | - | 24 | 10 | Note 3<br>435,67 | 432,34 |
| Lighting and Heating Transformers | 10 kVA | TIACF | 80 | 12 | - | 14 | 10 | 435,67 | 432,11 |
| People Lift | 7,5 kVA | ELEV | 50 | 11 | 88 | 14 | 4 | Note 3<br>435,67 | Note 3<br>431,56 |
| Auxiliaries of the Diesel Emergency Generator Set | 1,5 kVA | AGDE | 40 | 2 | - | 2 | 2,5 | 435,67 | 434,63 |
| Rotor Lifting System Pump | 3 cv | BSLR | 80 | 4,8 | 38,4 | 6 | 2,5 | Note 3<br>435,67 | Note 3<br>431,48 |
| Depletion Pumps of Draft Tube | 30 cv | MBEG | 30 | 40 | 320 | 50 | 10 | Note 3<br>435,67 | Note 3<br>431,66 |
| Fire Fighting Pumps | 50 cv | MBI | 30 | 65 | 520 | 81 | 25 | 413,36<br>435,67 | 404,47<br>432,90 |
| Overhead Crane | 75 cv | PRCF | 50 | 96 | Note 2 | 120 | 50 | 435,67 | 431,98 |

Note 1- The ventilation and exhaustion system consists of a set of fans and exhausters, totaling 75hp.
Note 2- The crane and gantry crane are driven by a speed control system. Therefore, it has no inrush current..
Note 3- Uncalculated values.

**Values for Transformer Primary Voltage 12.834V**

| CCG'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | CCG | Carga |
| Pow er Outlets | 30 kVA | TFCF | 80 | 36 | - | 41 | 25 | 435,67 | 431,23 |
| Mobile Insulating Oil Treatment System | 60 kVA | SMTOI | 80 | 72 | - | 83 | 50 | 435,67 | 430,94 |
| Mobile Lubricating Oil Treatment System | 30 kVA | SMTOL | 80 | 36 | - | 41 | 25 | 435,67 | 431,23 |
| Dow nstream Rolling Gantry | 15 kVA | PRJ | 50 | 18 | Note 2 | 21 | 10 | 435,67 | 432,34 |

Note 1- The ventilation and exhaustion system consists of a set of fans and exhausters, totaling 75hp.
Note 2- The crane and gantry crane are driven by a speed control system. Therefore, it has no inrush current..
Note 3- Uncalculated values.

**Values for Transformer Primary Voltage 12.834V**

| CCTA'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | CCTA | Carga |
| Lighting and Heating Transformers | 10 kVA | TIATA | 20 | 12 | - | 14 | 4 | 436,04 | 433,86 |
| Pow er Outlets | 30 kVA | TFTA | 80 | 36 | - | 41 | 25 | 436,04 | 407,94 |
| Upstream Rolling Gantry | 20 cv | PRTA | 50 | 27 | Note 1 | 31 | 10 | 436,04 | 431,59 |
| Pumps of the Hydraulic Pow er Unit of the Water Intake Gates | 15 cv | MBCTA | 20 | 21 | 168 | 26 | 4 | Note 2<br>436,04 | Note 2<br>432,76 |

Note 1- The gantry crane is driven by a speed control system. Therefore, it has no inrush current.
Note 2- Uncalculated values

**Values for Transformer Primary Voltage 12.834V**

| CCVT'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | CCTV | Carga |
| Lighting and Heating Transformers | 10 kVA | TIAVT | 20 | 12 | - | 14 | 4 | 435,43 | 433,25 |
| Pow er Outlets | 30 kVA | TFVT | 50 | 36 | - | 41 | 25 | 435,43 | 432,66 |
| Spillw ay Rolling Gantry | 15 cv | PRVT | 50 | 21 | Note 1 | 24 | 10 | 435,43 | 432,10 |
| Pumps of the Hydraulic Pow er Unit of the Spillw ay Gates | 7,5 cv | MBCVT | 20 | 11 | 88 | 14 | 2,5 | Note 2<br>435,43 | Note 2<br>432,82 |

Note 1- The gantry crane is driven by a speed control system. Therefore, it has no inrush current.
Note 2- Uncalculated values

**Values for Transformer Primary Voltage 12.834V**

| CCSE'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | CCSE | Carga |
| Lighting and Heating Transformers | 10 kVA | TIASE | 20 | 12 | - | 14 | 6 | 435,45 | 433,99 |
| Pow er Outlets | 30 kVA | TFSE | 50 | 36 | - | 41 | 25 | 435,45 | 432,68 |
| Motors of Sw itches and Circuit Breakers (1 Set) | 5cv | MDJCH | 80 | 7,6 | 60,8 | 10 | 6 | Note 1<br>435,45 | Note 1<br>432,52 |

Note 1- Uncalculated values
Note 2- It w as considered that of the set of sw itch-disconnectors and circuit-breaker compressors, only one motor operates at a time.

With one transformer feeding the entire load and 12,420V in the primary:

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCU's LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCU2 | Carga |
| Oil Pumps of Turbine's Speed Governor | 100 cv | MBORV | 35 | 124 | 1054 | 155 | 70 | 387,52<br>412,17 | 377,52<br>409,46 |
| Oil Circulation Pumps of Generator's Thrust and Guide Bearing | 10 cv | MBOMC | 25 | 14 | 112 | 17,5 | 4 | Note 1<br>412,17 | Note 1<br>409,28 |
| Oil Circulation Pumps of Turbine's Guide Bearing | 7,5 cv | MBOGT | 35 | 11 | 88 | 13,75 | 4 | Note 1<br>412,17 | Note 1<br>409,14 |
| Oil Injection Pumps of Thrust Bearing | 15 cv | MBIME | 25 | 21 | 168 | 26,25 | 6 | Note 1<br>412,17 | Note 1<br>409,27 |
| Turbine Cover Draining Pumps | 3 cv | MBDTT | 35 | 4,8 | 38,4 | 6 | 2,5 | Note 1<br>412,17 | Note 1<br>409,92 |
| Generator Heating Resistors | 15 kW | RAG | 25 | 18 | - | 20,7 | 6 | 412,17 | 409,73 |
| Turbine Well Oil Steam Exhauster | 0,5 cv | MEVT | 35 | 1,1 | 8,8 | 1,375 | 2,5 | Note 1<br>412,17 | Note 1<br>411,85 |
| Pumps or Valve of Unit Cooling Water System | 1,5 cv | MVAR | 35 | 3 | 24 | 3,75 | 2,5 | Note 1<br>412,17 | Note 1<br>411,21 |
| Generator Excitation Cubicle | 10 kVA | CEX | 25 | 12 | - | 13,8 | 4 | Note 1<br>412,17 | Note 1<br>409,28 |
| Auxiliaries of Step-Up Transformer | 30 kVA | ATE | 50 | 40 | 320 | 50 | 25 | 412,17 | 409,24 |
| Cooling Water System Self-Cleaning Filter | 1,5 cv | FALR | 35 | 3 | 24 | 3,75 | 2,5 | Note 1<br>412,17 | Note 1<br>411,21 |
| Note 1 - Uncalculated values. | | | | | | | | | |

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCG'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCG | Carga |
| Drainage Pumps | 20 cv | MBDE | 30 | 27 | 216 | 34 | 6 | Note 3<br>412,29 | Note 3<br>407,62 |
| Air Compressors of Speed Governor | 30 cv | MCARV | 30 | 40 | 320 | 50 | 10 | Note 3<br>412,29 | Note 3<br>408,05 |
| Ventilation and Exhaust System (1 Set) | 75 cv | MVE | 50 | 96 | Note 1 | 120 | 50 | 412,29 | 408,39 |
| Air Conditioning System | 30 cv | SAC | 50 | 40 | 320 | 50 | 10 | Note 3<br>412,29 | Note 3<br>405,17 |
| Service Air Compressors | 15 cv | MCAS | 30 | 21 | 168 | 26 | 4 | Note 3<br>412,29 | Note 3<br>407,06 |
| Telecommunications System | 10 kVA | TELE | 50 | 12 | - | 14 | 6 | 412,29 | 408,41 |
| Battery Chargers | 15 kVA | CBT | 50 | 21 | - | 24 | 10 | 412,29 | 408,76 |
| Lighting and Heating Transformers | 10 kVA | TIACF | 80 | 12 | - | 14 | 10 | 412,29 | 408,53 |
| People Lift | 7,5 kVA | ELEV | 50 | 11 | 88 | 14 | 4 | Note 3<br>412,29 | Note 3<br>407,94 |
| Auxiliaries of the Diesel Emergency Generator Set | 1,5 kVA | AGDE | 40 | 2 | - | 2 | 2,5 | 412,29 | 411,19 |
| Rotor Lifting System Pump | 3 cv | BSLR | 80 | 4,8 | 38,4 | 6 | 2,5 | Note 3<br>412,29 | Note 3<br>407,85 |
| Depletion Pumps of Draft Tube | 30 cv | MBEG | 30 | 40 | 320 | 50 | 10 | Note 3<br>412,29 | Note 3<br>408,05 |
| Fire Fighting Pumps | 50 cv | MBI | 30 | 65 | 520 | 81 | 25 | 400,88<br>412,29 | 392,26<br>409,36 |
| Overhead Crane | 75 cv | PRCF | 50 | 96 | Note 2 | 120 | 50 | 412,29 | 408,39 |
| Note 1- The ventilation and exhaustion system consists of a set of fans and exhausters, totaling 75hp.<br>Note 2- The crane and gantry crane are driven by a speed control system. Therefore, it has no inrush current..<br>Note 3- Uncalculated values. | | | | | | | | | |

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCG'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCG | Carga |
| Power Outlets | 30 kVA | TFCF | 80 | 36 | - | 41 | 25 | 412,29 | 407,59 |
| Mobile Insulating Oil Treatment System | 60 kVA | SMTOI | 80 | 72 | - | 83 | 50 | 412,29 | 407,28 |
| Mobile Lubricating Oil Treatment System | 30 kVA | SMTOL | 80 | 36 | - | 41 | 25 | 412,29 | 407,59 |
| Downstream Rolling Gantry | 15 kVA | PRJ | 50 | 18 | Note 2 | 21 | 10 | 412,29 | 408,76 |

Note 1- The ventilation and exhaustion system consists of a set of fans and exhausters, totaling 75hp.
Note 2- The crane and gantry crane are driven by a speed control system. Therefore, it has no inrush current..
Note 3- Uncalculated values.

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCTA'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCTA | Carga |
| Lighting and Heating Transformers | 10 kVA | TIATA | 20 | 12 | - | 14 | 4 | 412,75 | 410,45 |
| Power Outlets | 30 kVA | TFTA | 80 | 36 | - | 41 | 25 | 412,75 | 382,76 |
| Upstream Rolling Gantry | 20 cv | PRTA | 50 | 27 | Note 1 | 31 | 10 | 412,75 | 408,04 |
| Pumps of the Hydraulic Power Unit of the Water Intake Gates | 15 cv | MBCTA | 20 | 21 | 168 | 26 | 4 | Note 2<br>412,75 | Note 2<br>409,28 |

Note 1- The gantry crane is driven by a speed control system. Therefore, it has no inrush current.
Note 2- Uncalculated values

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCVT'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCTV | Carga |
| Lighting and Heating Transformers | 10 kVA | TIAVT | 20 | 12 | - | 14 | 4 | 413,11 | 410,81 |
| Power Outlets | 30 kVA | TFVT | 50 | 36 | - | 41 | 25 | 413,11 | 410,19 |
| Spillway Rolling Gantry | 15 cv | PRVT | 50 | 21 | Note 1 | 24 | 10 | 413,11 | 409,59 |
| Pumps of the Hydraulic Power Unit of the Spillway Gates | 7,5 cv | MBCVT | 20 | 11 | 88 | 14 | 2,5 | Note 2<br>413,11 | Note 2<br>410,36 |

Note 1- The gantry crane is driven by a speed control system. Therefore, it has no inrush current.
Note 2- Uncalculated values

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCSE'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 1TSA | |
| | | | | | | | | CCSE | Carga |
| Lighting and Heating Transformers | 10 kVA | TIASE | 20 | 12 | - | 14 | 6 | 412,19 | 410,65 |
| Power Outlets | 30 kVA | TFSE | 50 | 36 | - | 41 | 25 | 412,19 | 409,26 |
| Motors of Switches and Circuit Breakers (1 Set) | 5cv | MDJCH | 80 | 7,6 | 60,8 | 10 | 6 | Note 1<br>412,19 | Note 1<br>409,09 |

Note 1- Uncalculated values
Note 2- It was considered that of the set of switch-disconnectors and circuit-breaker compressors, only one motor operates at a time.

With two transformers feeding the entire load and 12,420V on the primary:

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCU's LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
| | | | | | | | | CCU2 | Carga |
| Oil Pumps of Turbine's Speed Governor | 100 cv | MBORV | 35 | 124 | 1054 | 155 | 70 | 395,93<br>420,91 | 385,71<br>418,25 |
| Oil Circulation Pumps of Generator's Thrust and Guide Bearing | 10 cv | MBOMC | 25 | 14 | 112 | 17,5 | 4 | Note 1<br>420,91 | Note 1<br>418,08 |
| Oil Circulation Pumps of Turbine's Guide Bearing | 7,5 cv | MBOGT | 35 | 11 | 88 | 13,75 | 4 | Note 1<br>420,91 | Note 1<br>417,94 |
| Oil Injection Pumps of Thrust Bearing | 15 cv | MBIME | 25 | 21 | 168 | 26,25 | 6 | Note 1<br>420,91 | Note 1<br>418,07 |
| Turbine Cover Draining Pumps | 3 cv | MBDTT | 35 | 4,8 | 38,4 | 6 | 2,5 | Note 1<br>420,91 | Note 1<br>418,70 |
| Generator Heating Resistors | 15 kW | RAG | 25 | 18 | - | 20,7 | 6 | 420,91 | 418,41 |
| Turbine Well Oil Steam Exhauster | 0,5 cv | MEVT | 35 | 1,1 | 8,8 | 1,375 | 2,5 | Note 1<br>420,91 | Note 1<br>420,60 |
| Pumps or Valve of Unit Cooling Water System | 1,5 cv | MVAR | 35 | 3 | 24 | 3,75 | 2,5 | Note 1<br>420,91 | Note 1<br>419,97 |
| Generator Excitation Cubicle | 10 kVA | CEX | 25 | 12 | - | 13,8 | 4 | Note 1<br>420,91 | Note 1<br>418,08 |
| Auxiliaries of Step-Up Transformer | 30 kVA | ATE | 50 | 40 | 320 | 50 | 25 | 420,91 | 418,05 |
| Cooling Water System Self-Cleaning Filter | 1,5 cv | FALR | 35 | 3 | 24 | 3,75 | 2,5 | Note 1<br>420,91 | Note 1<br>419,97 |

Note 1 - Uncalculated values

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCG'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
| | | | | | | | | CCG | Carga |
| Drainage Pumps | 20 cv | MBDE | 30 | 27 | 216 | 34 | 6 | Note 3<br>421,01 | Note 3<br>416,44 |
| Air Compressors of Speed Governor | 30 cv | MCARV | 30 | 40 | 320 | 50 | 10 | Note 3<br>421,01 | Note 3<br>416,86 |
| Ventilation and Exhaust System (1 Set) | 75 cv | MVE | 50 | 96 | Note 1 | 120 | 50 | 421,01 | 417,19 |
| Air Conditioning System | 30 cv | SAC | 50 | 40 | 320 | 50 | 10 | Note 3<br>421,01 | Note 3<br>414,04 |
| Service Air Compressors | 15 cv | MCAS | 30 | 21 | 168 | 26 | 4 | Note 3<br>421,01 | Note 3<br>415,89 |
| Telecommunications System | 10 kVA | TELE | 50 | 12 | - | 14 | 6 | 421,01 | 417,21 |
| Battery Chargers | 15 kVA | CBT | 50 | 21 | - | 24 | 10 | 421,01 | 417,56 |
| Lighting and Heating Transformers | 10 kVA | TIACF | 80 | 12 | - | 14 | 10 | 421,01 | 417,33 |
| People Lift | 7,5 kVA | ELEV | 50 | 11 | 88 | 14 | 4 | Note 3<br>421,01 | Note 3<br>416,75 |
| Auxiliaries of the Diesel Emergency Generator Set | 1,5 kVA | AGDE | 40 | 2 | - | 2 | 2,5 | 421,01 | 419,93 |
| Rotor Lifting System Pump | 3 cv | BSLR | 80 | 4,8 | 38,4 | 6 | 2,5 | Note 3<br>421,01 | Note 3<br>416,67 |
| Depletion Pumps of Draft Tube | 30 cv | MBEG | 30 | 40 | 320 | 50 | 10 | Note 3<br>421,01 | Note 3<br>416,86 |
| Fire Fighting Pumps | 50 cv | MBI | 30 | 65 | 520 | 81 | 25 | 399,60<br>421,01 | 391,01<br>418,15 |
| Overhead Crane | 75 cv | PRCF | 50 | 96 | Note 2 | 120 | 50 | 421,01 | 417,19 |

Note 1- The ventilation and exhaustion system consists of a set of fans and exhausters, totaling 75hp.
Note 2- The crane and gantry crane are driven by a speed control system. Therefore, it has no inrush current..
Note 3- Uncalculated values

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCG'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
| | | | | | | | | CCG | Carga |
| Power Outlets | 30 kVA | TFCF | 80 | 36 | - | 41 | 25 | 421,01 | 416,41 |
| Mobile Insulating Oil Treatment System | 60 kVA | SMTOI | 80 | 72 | - | 83 | 50 | 421,01 | 416,11 |
| Mobile Lubricating Oil Treatment System | 30 kVA | SMTOL | 80 | 36 | - | 41 | 25 | 421,01 | 416,41 |
| Downstream Rolling Gantry | 15 kVA | PRJ | 50 | 18 | Note 2 | 21 | 10 | 421,01 | 417,56 |

Note 1- The ventilation and exhaustion system consists of a set of fans and exhausters, totaling 75hp.
Note 2- The crane and gantry crane are driven by a speed control system. Therefore, it has no inrush current..
Note 3- Uncalculated values

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCTA'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
| | | | | | | | | CCTA | Carga |
| Lighting and Heating Transformers | 10 kVA | TIATA | 20 | 12 | - | 14 | 4 | 421,41 | 419,15 |
| Power Outlets | 30 kVA | TFTA | 80 | 36 | - | 41 | 25 | 421,41 | 392,16 |
| Upstream Rolling Gantry | 20 cv | PRTA | 50 | 27 | Note 1 | 31 | 10 | 421,41 | 416,80 |
| Pumps of the Hydraulic Power Unit of the Water Intake Gates | 15 cv | MBCTA | 20 | 21 | 168 | 26 | 4 | Note 2<br>421,41 | Note 2<br>418,02 |

Note 1- The gantry crane is driven by a speed control system. Therefore, it has no inrush current.
Note 2- Uncalculated values

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCVT'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
| | | | | | | | | CCTV | Carga |
| Lighting and Heating Transformers | 10 kVA | TIAVT | 20 | 12 | - | 14 | 4 | 420,83 | 418,57 |
| Power Outlets | 30 kVA | TFVT | 50 | 36 | - | 41 | 25 | 420,83 | 417,96 |
| Spillway Rolling Gantry | 15 cv | PRVT | 50 | 21 | Note 1 | 24 | 10 | 420,83 | 417,38 |
| Pumps of the Hydraulic Power Unit of the Spillway Gates | 7,5 cv | MBCVT | 20 | 11 | 88 | 14 | 2,5 | Note 2<br>420,83 | Note 2<br>418,13 |

Note 1- The gantry crane is driven by a speed control system. Therefore, it has no inrush current.
Note 2- Uncalculated values

| Values for Transformer Primary Voltage 12.420V | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CCSE'S LOADS | Power | TAG | l(m) | In (A) | Ip (A) | Icable (A) | S (mm2) | Voltages - 2TSA | |
| | | | | | | | | CCSE | Carga |
| Lighting and Heating Transformers | 10 kVA | TIASE | 20 | 12 | - | 14 | 6 | 420,87 | 419,36 |
| Power Outlets | 30 kVA | TFSE | 50 | 36 | - | 41 | 25 | 420,87 | 418,01 |
| Motors of Switches and Circuit Breakers (1 Set) | 5cv | MDJCH | 80 | 7,6 | 60,8 | 10 | 6 | Note 1<br>420,87 | Note 1<br>417,84 |

Note 1- Uncalculated values
Note 2- It was considered that of the set of switch-disconnectors and circuit-breaker compressors, only one motor operates at a time.

5.4.2.7. Evaluation of Results

By the calculated voltage values, it is verified that the lowest voltage in the motors of 100hp, during the starting, will be:

- 391.00V in motors powered by CCU2, when a single auxiliary service transformer is feeding the entire load of the plant, and when the primary voltage of the transformer is with the minimum value of the appropriate voltage (12.834V).

- 385.71V, in motors powered by CCU2, when two auxiliary service transformers are feeding the entire load of the plant, and when the primary voltage of the transformer is with the minimum value of the precarious voltage (12.420V).

- 377.52V in the motors powered by CCU2, when a single auxiliary service transformer is feeding the entire load of the plant, and when the primary voltage of the transformer is with the minimum value of the precarious voltage (12.420V).

Therefore, it is concluded that for the appropriate voltage range, the minimum voltages will be met, even when a single transformer is feeding the entire load of the plant. For the case of a single transformer feeding the entire load of the plant, with the minimum value of the precarious voltage in the primary, transient problems may occur during the start of the 100hp motors and, for the 50hp motors of the CCG Load Center, the minimum voltage in the motors during start-up will be 392.26V.

The values mentioned above were obtained considering the use of the tap of the primary winding of the transformer, corresponding to the nominal voltage, that is, 13,800V.

5.4.2.8. Applicable Alternatives

As an alternative to the calculations made in this technical information, the professional can adopt other criteria to define the equipment and components, such as choosing another derivation of the primary winding of the auxiliary services transformer, using another derivation of the secondary winding of the step-up transformer, or defining another maximum voltage of the system, considering that the load of the plant will never be zero, etc.

In this item will be made a brief evaluation of the feasibility of an alternative different from the one used in this informative.

In the application developed in this information it could be anticipated, in case of minimum precarious voltage in the primary of the transformer, that in the terminals of the secondary of the transformer of auxiliary services, the minimum voltages of the equipment would not be met for all load conditions. For example, with the voltage of 12,420V in the primary of the transformer, with a single transformer feeding the maximum load of the plant and starting of the largest motor (100hp), the voltage in the secondary will be 395.26V, that is, so that the minimum starting voltage of the motor (391V) is met, the total voltage drop, from the transformer to the motor, should be 4.26V.

With the calculations made, the voltage in the motor of 100hp, at the start, will be 377.52V with a total voltage drop of 17.74V, that is, 82% of the nominal voltage of the motor instead of 85%. With the voltage of 377.52V the motor will depart, mainly because it is the motor of a pump. However, the minimum voltage requirement will not be met.

Taking advantage of the quick estimate that was made, it was found that, to meet the value of the minimum voltage during the start of the 100hp motor, the voltage in the secondary of the transformer should be 409.87V, instead of the 395.26V calculated for the 1000kVA transformer, with the voltage of 12,420V in the primary.

Considering the same conditions, the voltage at the secondary terminals of a 1500kVA transformer, with an impedance of 6%, will be 407.39V.

Considering the same conditions, the voltage at the secondary terminals of a 1500kVA transformer, with an impedance of 6%, will be 407.39V.

| 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) | 1500 |
| | $Z_n$ | Rated Impedance of Transformer (%) | 6 |
| | $R_n$ | Rated Resistence of Transformer (%) | 1 |
| | $V_P$ | Primary Voltage on Transformer (kV) | 12,42 |
| | $k$ | Tap Voltage Used of Transformer (pu) | 1 |
| Loads Data | $Pc_{Kn}$ | Rated Power of Constant Load (kVA) | 550 |
| | $Vc_{Kn}$ | Rated Voltage of Constant Load (V) | 460 |
| | $FPc_K$ | Power Factor of Constant Load | 0,85 |
| | $Pc_{Vn}$ | Rated Power of Variable Load (kVA) | 150 |
| | $Vc_{Vn}$ | Rated Voltage of Variable Load (V) | 480 |
| | $FPc_V$ | Power Factor of Variable Load | 0,9 |
| | $VM_{pn}$ | 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)* | 407,39 |

As the value is very close to what is needed, we will make a change in the sections of the feeders involved, to compensate for this voltage difference.

Making the calculations to compensate for this voltage drop in the feeder cables of the motors and, recalculating the voltage in CCU2, which is the center of loads with lower voltage, for the feeder with the same 2 cables per phase of 95mm2, we will find the voltage of 399.49V:

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,05 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,231 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 2 |
| | $V_F$ | Source Voltage (V) | 407,39 |
| Cargo Data | $PC_{Kn}$ | Rated Power of the Constant Load (kVA) | 80 |
| | $VC_{Kn}$ | Rated Voltage of the Constant Load (V) | 460 |
| | $FPC_K$ | Power Factor of the Constant Load | 0,85 |
| | $PC_{Vn}$ | Rated Power of the Variable Load (kVA) | 20 |
| | $VC_{Vn}$ | Rated Voltage of the Variable Load (V) | 480 |
| | $FPC_V$ | Power Factor of the Variable Load | 0,9 |
| | $VM_{Pn}$ | Rated Voltage of the Motor(s) (V) | 460 |
| | $IM_{Pn}$ | Starting Current of Motor(s) at Rated Voltage (A) | 1054 |
| | $FPM_P$ | Power Factor of the Motor(s) at Starting | 0,3 |

| | | |
|---|---|---|
| $VC_T$ | *Load voltage considering the defined source voltage* | 399,49 |

Changing the section of the feeder cable of the motor, from 70mm$^2$ to 120mm$^2$, the voltage at the motor terminals, during the starting will be 391.45V.

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,035 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,183 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 1 |
| | $V_F$ | Source Voltage (V) | 399,49 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | |
| | $FP_{C_K}$ | Power Factor of the Constant Load | |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | |
| | $FP_{C_V}$ | Power Factor of the Variable Load | |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | 460 |
| | $I_{M_{Pn}}$ | Starting Current of Motor(s) at Rated Voltage (A) | 1054 |
| | $FP_{M_P}$ | Power Factor of the Motor(s) at Starting | 0,3 |

| | | |
|---|---|---|
| $V_{C_T}$ | *Load voltage considering the defined source voltage* | 391,45 |

This alternative can be evaluated as it is feasible, and the costs would not be too high. However, the calculations must be redone and the need for their implementation must be assessed.

5.4.2.9. Conclusion

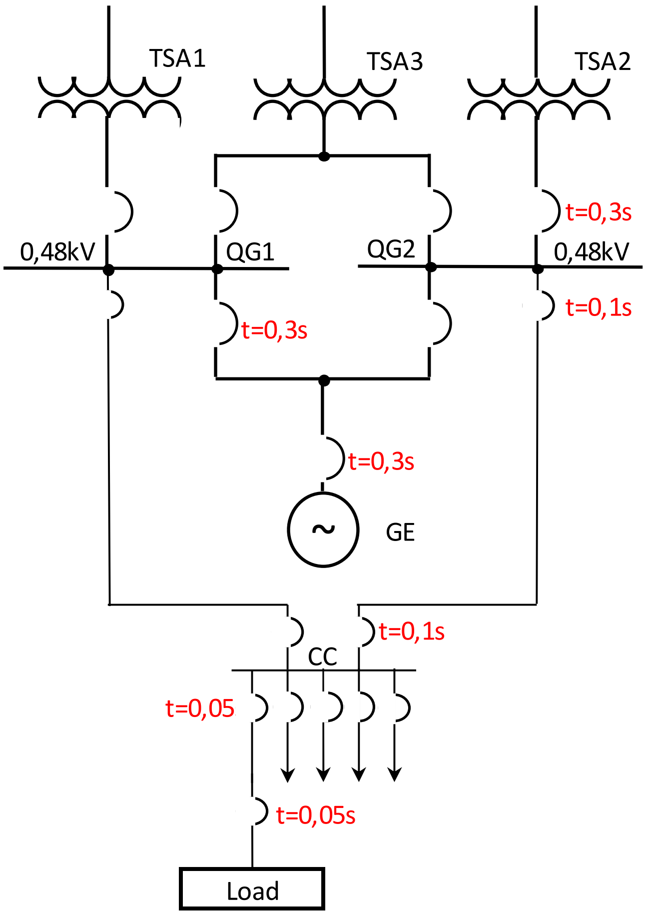
As can be seen, there are many solutions to solve the eventual problems in the definition of the electrical auxiliary systems of a hydroelectric power plant. However, to define the most appropriate it is necessary to be in possession of more information of the systems, such as voltages of the high voltage substation, transformers, elevators, criteria of operation of the installations, etc.

If the worst conditions are considered, such as minimum voltage of the high voltage substation, little power being supplied by the generators, only a single transformer auxiliary services feeding the installations with maximum load, etc., the only solution may be the recommendation to use auxiliary service transformers, equipped with automatic load tap changer for dry transformers, whose cost is very high, in addition to occupying spaces and requiring specialized maintenance.

In the definition of the solution adopted, any restrictions or limitations of operation should be considered, defining the solutions to any problems that may arise.

5.4.3 - Short Circuit

To size the circuits according to the short circuit currents will be considered the acting times of the protections indicated in the following figure:




The actuation times of the protection devices of the same circuit are the same. For example, if a defect occurs in the load, the two circuit breakers, of the load and the load center (CC) output will open; if a defect occurs in the load panel feeder, only the load center (CC) output circuit breaker will open. The QG output protection and load center (CC) input protection will operate in the same way.

The choice of cables will be made according to the criteria defined in the technical information TE.EL.SA.CA.05 Feeders – Criteria for Sizing and spreadsheet PL.EL.SA. CA.06 Feeders – Criteria for Dimensioning.

5.4.3.1. Emergency Diesel Generator Set

Calculating the short circuit current of the alternator, based on the Subtransient reactance of 8.41%, we have:

$$I_{CC} = \frac{605}{0{,}0841x0{,}480\sqrt{3}}$$

$$I_{CC} = 8.652{,}8A$$

Calculating the short circuit current of the alternator, based on the Subtransient reactance of 8.41%, we have:

$$S \geq \frac{I_{CC}}{k_\theta}\sqrt{t}$$

$$S \geq \frac{8652{,}8}{143}\sqrt{0{,}3}$$

$$S \geq 33{,}1mm^2 = 35mm^2$$

This section is smaller than that calculated by current conduction (2x120mm$^2$).

5.4.3.2. General Load Center

Depending on the power supply, the maximum short circuit power can be 16.7 or 16.4MVA, which correspond to the currents of 20.1kA and 19.7kA.

Considering the highest current, the minimum section of the feeder cables of the load centers, for the protection actuation time of 0.1s should be:

$$S \geq \frac{20.100}{143}\sqrt{0,1}$$

$$S \geq 44,5mm^2 = 50mm^2$$

As this section is inferior to the sections of the feeders of the load centers of the units and general (CCU1, CCU2, CCU3 and CCG), calculated by the criterion of current conduction and voltage drop, the verification of the feeders of the load centers of the water intake (CCTA), spillway (CCVT) and substation (CCSE) will be done.

By the criterion of minimum length of protected cable, it is verified that, according to the following table, for feeders with more than 38m of length and maximum time of action of the protection of 0.1s, any section of conductor meets the criterion of protection by the short circuit. Therefore, the feeders of the water intake load center (CCTA) which has 80m, the spillway load center (CCVT) which has 150m and the substation load center (CCSE) which has 150m, meet the criteria of the minimum length of protected cable.

| CABLES INSULATED WITH EPR/XLPE | | | | | | |
|---|---|---|---|---|---|---|
| System Nominal Voltage (Vn) | | | | | 480 | V |
| Maximum Voltage Factor (f) | | | | | 110 | % |
| Protected Cable Length (m) | | | | | | |
| Cables Data | | | Fault Interruption Time (s) | | | |
| $S\ (mm^2)$ | $R_{90}$ | $X_{60Hz}$ | 0,05 | 0,10 | 0,3 | 0,5 |
| 2,5 | 8,794 | 0,096 | 27 | 38 | 66 | 85 |
| 4 | 5,496 | 0,096 | 27 | 38 | 66 | 85 |
| 6 | 3,664 | 0,096 | 27 | 38 | 66 | 85 |
| 10 | 2,198 | 0,096 | 27 | 38 | 66 | 85 |
| 16 | 1,374 | 0,096 | 27 | 38 | 66 | 85 |
| 25 | 0,879 | 0,096 | 27 | 38 | 66 | 85 |
| 35 | 0,628 | 0,096 | 27 | 38 | 65 | 84 |
| 50 | 0,440 | 0,096 | 26 | 37 | 65 | 83 |
| 70 | 0,314 | 0,096 | 26 | 36 | 63 | 82 |
| 95 | 0,231 | 0,096 | 25 | 35 | 61 | 79 |
| 120 | 0,183 | 0,096 | 24 | 34 | 58 | 76 |
| 150 | 0,147 | 0,096 | 23 | 32 | 55 | 71 |
| 185 | 0,119 | 0,096 | 21 | 30 | 51 | 66 |
| 240 | 0,092 | 0,096 | 19 | 26 | 46 | 59 |

Based on the above, the sections of the following table, calculated by the criterion of current conduction and voltage drop, also meet the short circuit criteria.

| Load Center | CCU1 | CCU2 | CCU3 | CCG | CCTA | CCVT | CCSE |
|---|---|---|---|---|---|---|---|
| l(m) | 30 | 50 | 70 | 30 | 80 | 150 | 150 |
| Section $(mm^2)$ | 150 | 2x95 | 2x240 | 2x120 | 95 | 120 | 70 |

5.4.3.3. Load Centers

It was considered that all loads fed by the Load Centers (CC) have a local command and control panel, because the load centers are not equipped with these drive devices.

Considering that the actuation time of the protection, of the devices of the outputs of the load centers and local command and control panels, is 0.05s, all feeders with more than 26m in length, whatever the nominal section, are protected, for any short circuit power of the source. In this way, it is only necessary to check the feeders with a length of less than

26m. In this condition are the following circuits, whose sections indicated in blue color already meet the criteria of current conduction and voltage drop:

| CCU's LOADS | Power | TAG | l(m) | S (mm2) |
|---|---|---|---|---|
| Oil Circulation Pumps of Generator's Thrust and Guide Bearing | 10 cv | MBOMC | 25 | 4 |
| Oil Injection Pumps of Thrust Bearing | 15 cv | MBIME | 25 | 6 |
| Generator Heating Resistors | 15 kW | RAG | 25 | 6 |
| Generator Excitation Cubicle | 10 kVA | CEX | 25 | 4 |

| CCTA'S LOADS | Power | TAG | l(m) | S (mm2) |
|---|---|---|---|---|
| Lighting and Heating Transformers | 10 kVA | TIATA | 20 | 4 |
| Pumps of the Hydraulic Power Unit of the Water Intake Gates | 15 cv | MBCTA | 20 | 4 |

| CCVT'S LOADS | Power | TAG | l(m) | S (mm2) |
|---|---|---|---|---|
| Lighting and Heating Transformers | 10 kVA | TIAVT | 20 | 4 |
| Pumps of the Hydraulic Power Unit of the Spillway Gates | 7,5 cv | MBCVT | 20 | 2,5 |

| CCSE'S LOADS | Power | TAG | l(m) | S (mm2) |
|---|---|---|---|---|
| Lighting and Heating Transformers | 10 kVA | TIASE | 20 | 6 |

The short circuit powers in each of the load centers are indicated in the following table, calculated with the aid of the PL.EL.SA spreadsheet. CA.06, whose application is indicated only for the Load Center of Unit 1 (CCU1), which has the highest short circuit power:

| CABLES INSULATED WITH EPR/XLPE | | | | | |
|---|---|---|---|---|---|
| Source Short Circuit Power (Pcc) | | | | 16,7 | MVA |
| System Nominal Voltage (Vn) | | | | 480 | V |
| Maximum Voltage Factor (f) | | | | 110 | % |
| Feeder Length | | | | 30 | m |
| Cables Data | | | Short Circuit Current (KA) | Maximum Time for Protection to Operate (s) | |
| S | $R_{90}$ | $X_{60Hz}$ | | | |
| 120 | 0,183 | 0,096 | 17,36 | 0,98 | |

The short circuit current in CCU1 will be 17.36kA which corresponds to a short circuit power of:

$$P_{CC} = \sqrt{3}x0{,}48x17{,}36 = 14{,}43MVA$$

| Panel | $P_{CC}$ at Source (MVA) | Feeder Lenght (m) | Cable Section (mm$^2$) | $I_{CC}$ (kA) | $P_{CC}$ at CC (MVA) |
|---|---|---|---|---|---|
| CCU1 | 16,7 | 30 | 120 | 17,36 | 14,43 |
| CCTA | 16,7 | 80 | 25 | 4,14 | 3,44 |
| CCVT | 16,7 | 150 | 16 | 1,47 | 1,22 |
| CCSE | 16,7 | 150 | 10 | 1,47 | 1,22 |

With the short circuit power in the load center, one can calculate the short circuit current at the end of the load circuit cable and the maximum acting time of the protection that guarantees the feeder cable protection. This calculation will be done with the help of the spreadsheet PL.EL.SA. CA.06, only for loads from the circuits of the Unit 1 Load Center (CCU1):

| CABLES INSULATED WITH EPR/XLPE | | | | | |
|---|---|---|---|---|---|
| Source Short Circuit Power (Pcc) | | | | 14,43 | MVA |
| System Nominal Voltage (Vn) | | | | 480 | V |
| Maximum Voltage Factor (f) | | | | 110 | % |
| Feeder Length | | | | 25 | m |
| Cables Data | | | Short Circuit Current (KA) | Maximum Time for Protection to Operate (s) | |
| S | $R_{90}$ | $X_{60Hz}$ | | | |
| 4 | 5,496 | 0,096 | 2,20 | 0,07 | |
| 6 | 3,664 | 0,096 | 3,26 | 0,07 | |

| Load Center | $P_{CC}$ at CC (MVA) | Load | Power | TAG | l(m) | S (mm2) | $I_{CC}$ at Load (kA) | Maximum Protection Time (s) |
|---|---|---|---|---|---|---|---|---|
| CCU | 14,43 | Oil Circulation Pumps of Generator's Thrust and Guide Bearing | 10 cv | MBOMC | 25 | 4 | 2,20 | 0,07 |
| | | Oil Injection Pumps of Thrust Bearing | 15 cv | MBIME | 25 | 6 | 3,26 | 0,07 |
| | | Generator Heating Resistors | 15 kW | RAG | 25 | 6 | 3,26 | 0,07 |
| | | Generator Excitation Cubicle | 10 kVA | CEX | 25 | 4 | 2,20 | 0,07 |
| CCTA | 3,44 | Lighting and Heating Transformers | 10 kVA | TIATA | 20 | 4 | 1,98 | 0,08 |
| | | Pumps of the Hydraulic Power Unit of the Water Intake Gates | 15 cv | MBCTA | 20 | 4 | 1,98 | 0,08 |
| CCTV | 1,22 | Lighting and Heating Transformers | 10 kVA | TIAVT | 20 | 4 | 1,29 | 0,20 |
| | | Pumps of the Hydraulic Power Unit of the Spillway Gates | 7,5 cv | MBCVT | 20 | 2,5 | 1,05 | 0,12 |
| CCSE | 1,22 | Lighting and Heating Transformers | 10 kVA | TIASE | 20 | 6 | 1,44 | 0,36 |

Therefore, the cables selected by the current conduction criterion, and altered and/or confirmed by the voltage drop criterion, meet the short circuit criteria.

## 6 - RELEVANT EVALUATIONS

As we have seen there are many resources to perform the calculations of the components of the systems, some are more accurate than others, but it will always be possible to increase that precision. As an example of this approximation we can mention that, in the spreadsheet of the calculation of the voltage drop in the transformers, as stated in the theoretical information that is the origin of the spreadsheet, in the impedance of the transformer $Z = R + jX$, the value of the resistance was considered to be 1% and the impedance, specified of the transformer, as the value of $Z$. The reactance $X$ or impedance $Z$ value is obtained from this relationship. Therefore, the calculation using the spreadsheet is also an approximation.

The values of the resistances and reactances of the cables also depend on many variables and their values are difficult to obtain precisely. The installation conditions, grouping factors, actual operating temperatures of the cables as a function of the loads, ambient temperature and other variables make it difficult to define the values.

Loads, in turn, are also information that depend on valuations. For example, a pump is sized to meet the extreme operating condition, with estimated throughput and with a design or safety factor. The motor is also selected with an estimated yield, with power within the standardized values and sometimes with service factor that is not considered. Therefore, depending on the actual operating conditions, the motors operate with loads lower than those that are considered in the design and sizing of the circuits.

Each professional has their experiences and preferences and, based on them and their client's requirements, must develop the project. The technical information and spreadsheets are the tools that facilitate and expedite the realization of the studies of the alternatives.

## 7 - APPLICATION OF APPROXIMATE CALCULATIUONS

In this item will be addressed some concepts of the book Industrial Power Systems Handbook, by Donald Beeman, which is a reference for professionals around electrical engineering, especially when there were no computer resources that are available today.

### 7.1 - Analysis of Approximate Calculations

To perform approximate calculations there are tables, graphs, formulas, etc. that provide the necessary information. One of these tools, widely used is the formula:

$$\Delta V = \sqrt{3}\, I(Rcos\varphi + Xsen\varphi)$$

$\Delta V$ Voltage drops (V)

$I$ Load current (A)

$R$ Feeder resistance (Ω)

$X$ Feeder reactance (Ω)

$\varphi$ Load current angle.

7.1.1 - Approximate Calculation of Load Voltage

We will use the example below to compare the results, that is:

Calculate the voltage at the terminals of a motor during direct start, full voltage, when the voltage at the source is 480V, considering that the motor is feed by cables of 95mm$^2$, with a length of 160m.

Motor Data:

Rated Power 100hp

Rated voltage 460V

Starting current 1054A

Starting power factor 0.3

Knowing that, under the conditions of installation, the values of $R_a$ and $X_a$ are:

$$R_a = 0{,}231\Omega/km$$

$$X_a = 0{,}096\Omega/km$$

**Solution:**

$$R = 0{,}231x0{,}16 = 0{,}0370\Omega$$

$$X = 0{,}096x0{,}16 = 0{,}0154\Omega$$

$$cos\varphi = 0{,}3$$

$$sen\varphi = 0{,}953939$$

$$\sqrt{3}\,(Rcos\varphi + Xsen\varphi) = 0{,}0447$$

As the voltage at the source is 480V, the motor current corrected for this voltage will be:

$$I = 1054\frac{480}{460} = 1099{,}83$$

So:

$$\Delta V = \sqrt{3}\, I(Rcos\varphi + Xsen\varphi) = 1099{,}83x0{,}0447 = 49{,}16V$$

The voltage in the load would be:

$$V_C = 480 - 49{,}16 = 430{,}84V$$

As directed by Beeman, we will recalculate the voltage drop by correcting the current to the voltage found in the load and obtain:

$$I = 1054\frac{430{,}84}{460} = 987{,}19A$$

The new voltage drop will be:

$\Delta V = \sqrt{3}\, I(Rcos\varphi + Xsen\varphi) = 987{,}19x0{,}447 = 44{,}13V$

Finally, the voltage in the load will be:

$V_C = 480 - 44{,}13 = 435{,}87V$

In the calculation, with the aid of the spreadsheet, the voltage found was 432.88V.

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,16 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,231 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 1 |
| | $V_F$ | Source Voltage (V) | 480 |
| Cargo Data | $PC_{Kn}$ | Rated Power of the Constant Load (kVA) | |
| | $VC_{Kn}$ | Rated Voltage of the Constant Load (V) | |
| | $FPC_K$ | Power Factor of the Constant Load | |
| | $PC_{Vn}$ | Rated Power of the Variable Load (kVA) | |
| | $VC_{Vn}$ | Rated Voltage of the Variable Load (V) | |
| | $FPC_V$ | Power Factor of the Variable Load | |
| | $VM_{Pn}$ | Rated Voltage of the Motor(s) (V) | 460 |
| | $IM_{Pn}$ | Starting Current of Motor(s) at Rated Voltage (A) | 1054 |
| | $FPM_P$ | Power Factor of the Motor(s) at Starting | 0,3 |

| | | |
|---|---|---|
| $VC_T$ | *Load voltage considering the defined source voltage* | 432,88 |

As can be seen, the calculation can be done quite approximately, with simple formulas, compatible with limited calculation resources.

7.1.2 - Approximate Calculation of the Voltage at the Source

We will use the example below to compare the results, that is:

Calculate the voltage at the source so that the voltage in the motor is 432.88 V during direct start-up, at full voltage, considering that the motor is powered by 95mm$^2$ cables, with a length of 160m.

Motor Data:

Rated Power 100hp

Rated voltage 460V

Starting current 1054A

Starting power factor 0.3

Knowing that, under the conditions of installation, the values of $R_a$ and $X_a$ are:

$R_a = 0{,}231\Omega/km$

$X_a = 0{,}096\Omega/km$

**Solution:**

$R = 0{,}231x0{,}16 = 0{,}0370\Omega$

$X = 0{,}096x0{,}16 = 0{,}0154\Omega$

$cos\varphi = 0{,}3$

$sen\varphi = 0{,}953939$

$\sqrt{3}\,(Rcos\varphi + Xsen\varphi) = 0{,}0447$

As the voltage at load is 435.87V, the motor current corrected for this voltage will be:

$$I = 1054\frac{435{,}87}{460} = 998{,}71A$$

So:

$$\Delta V = \sqrt{3}\, I(Rcos\varphi + Xsen\varphi) = 998{,}71x0{,}0447 = 44{,}64V$$

The voltage at the source will be:

$$V_F = 435{,}87 - 44{,}64 = 480{,}51V$$

In the calculation, with the aid of the spreadsheet, the voltage found was 480.00V.

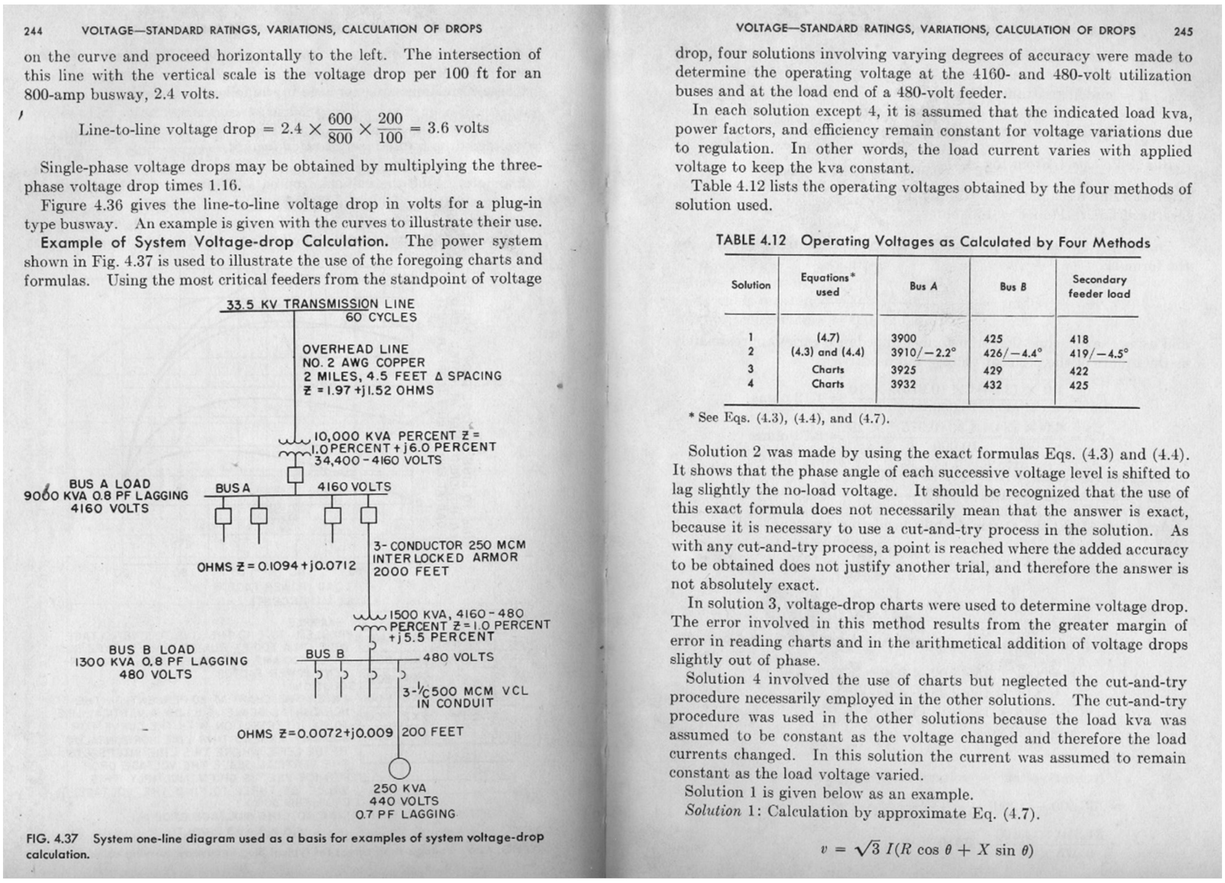
| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Circuit Length (km) | 0,16 |
| | $R\,a$ | Cable Resistance (Ω/km) | 0,231 |
| | $X\,a$ | Cable Reactance (Ω/km) | 0,096 |
| | $n$ | Number of Cables per Phase | 1 |
| | $V\,C_T$ | Voltage on the Load (V) | 432,88 |
| Cargo Data | $P\,C_{Kn}$ | Rated Power of the Constant Load (kVA) | |
| | $V\,C_{Kn}$ | Rated Voltage of the Constant Load (V) | |
| | $FP\,C_K$ | Power Factor of the Constant Load | |
| | $P\,C_{Vn}$ | Rated Power of the Variable Load (kVA) | |
| | $V\,C_{Vn}$ | Rated Voltage of the Variable Load (V) | |
| | $FP\,C_V$ | Power Factor of the Variable Load | |
| | $V\,M_{Pn}$ | Rated Voltage of the Motor(s) (V) | 460 |
| | $I\,M_{Pn}$ | Starting Current of the Motor(s) at Rated Voltage (A) | 1054 |
| | $FP\,M_P$ | Fator de Potência do(s) Motor(es) na Partida | 0,3 |

| | | |
|---|---|---|
| $V_F$ | Source voltage considering the defined load voltage | 480,00 |

## 7.2 - Problem and Solution

Next, a problem from Donald Beeman's book will be solved using the spreadsheets, and the result will be compared.

The problem is presented in the texts of the following images:



244 VOLTAGE—STANDARD RATINGS, VARIATIONS, CALCULATION OF DROPS

on the curve and proceed horizontally to the left. The intersection of this line with the vertical scale is the voltage drop per 100 ft for an 800-amp busway, 2.4 volts.

$$\text{Line-to-line voltage drop} = 2.4 \times \frac{600}{800} \times \frac{200}{100} = 3.6 \text{ volts}$$

Single-phase voltage drops may be obtained by multiplying the three-phase voltage drop times 1.16.

Figure 4.36 gives the line-to-line voltage drop in volts for a plug-in type busway. An example is given with the curves to illustrate their use.

**Example of System Voltage-drop Calculation.** The power system shown in Fig. 4.37 is used to illustrate the use of the foregoing charts and formulas. Using the most critical feeders from the standpoint of voltage



FIG. 4.37 System one-line diagram used as a basis for examples of system voltage-drop calculation.

VOLTAGE—STANDARD RATINGS, VARIATIONS, CALCULATION OF DROPS 245

drop, four solutions involving varying degrees of accuracy were made to determine the operating voltage at the 4160- and 480-volt utilization buses and at the load end of a 480-volt feeder.

In each solution except 4, it is assumed that the indicated load kva, power factors, and efficiency remain constant for voltage variations due to regulation. In other words, the load current varies with applied voltage to keep the kva constant.

Table 4.12 lists the operating voltages obtained by the four methods of solution used.

TABLE 4.12 Operating Voltages as Calculated by Four Methods

| Solution | Equations* used | Bus A | Bus B | Secondary feeder load |
|---|---|---|---|---|
| 1 | (4.7) | 3900 | 425 | 418 |
| 2 | (4.3) and (4.4) | $3910\angle{-2.2°}$ | $426\angle{-4.4°}$ | $419\angle{-4.5°}$ |
| 3 | Charts | 3925 | 429 | 422 |
| 4 | Charts | 3932 | 432 | 425 |

* See Eqs. (4.3), (4.4), and (4.7).

Solution 2 was made by using the exact formulas Eqs. (4.3) and (4.4). It shows that the phase angle of each successive voltage level is shifted to lag slightly the no-load voltage. It should be recognized that the use of this exact formula does not necessarily mean that the answer is exact, because it is necessary to use a cut-and-try process in the solution. As with any cut-and-try process, a point is reached where the added accuracy to be obtained does not justify another trial, and therefore the answer is not absolutely exact.

In solution 3, voltage-drop charts were used to determine voltage drop. The error involved in this method results from the greater margin of error in reading charts and in the arithmetical addition of voltage drops slightly out of phase.

Solution 4 involved the use of charts but neglected the cut-and-try procedure necessarily employed in the other solutions. The cut-and-try procedure was used in the other solutions because the load kva was assumed to be constant as the voltage changed and therefore the load currents changed. In this solution the current was assumed to remain constant as the load voltage varied.

Solution 1 is given below as an example.

*Solution* 1: Calculation by approximate Eq. (4.7).

$$v = \sqrt{3}\, I(R \cos\theta + X \sin\theta)$$

where $v$ = line-to-line voltage drop
$I$ = line current, amp
$R$ = circuit resistance, ohms
$X$ = circuit reactance, ohms
$\theta$ = load power-factor angle

*Bus A Voltage.* From Fig. 4.37,

Overhead line resistance = 1.97 ohms
Overhead line reactance = 1.52 ohms

Converting transformer per cent resistance and reactance to ohms by the formula

$$\text{Ohms} = \frac{\%\ \text{ohms} \times (\text{kv})^2 \times 10}{\text{kva}}$$

and using the principle that transformer impedance varies approximately as the square of the per cent voltage tap used,

$$R_T = \frac{1.0 \times (34.4)^2 \times (0.975)^2 \times 10}{10{,}000} = 1.12 \text{ ohms}$$

$$X_T = \frac{6.0 \times (34.4)^2 \times (0.975)^2 \times 10}{10{,}000} = 6.73 \text{ ohms}$$

Total ohms resistance = 1.97 + 1.12 = 3.09
Total ohms reactance = 1.52 + 6.73 = 8.25

Assuming 4160 volts at bus $A$ and considering constant load,

$$\text{Bus } A \text{ amperes} = \frac{9000 \text{ kva}}{\sqrt{3} \times 4.160} = 1250$$

$$\text{Overhead line amperes} = \frac{1250 \times 4.16}{34.4 \times .975} = 155$$

Substituting in the voltage-drop formula with $\cos\theta = 0.8$ and $\sin\theta = 0.6$,

$$\begin{aligned} v &= \sqrt{3} \times 155(3.09 \times 0.8 + 8.25 \times 0.6) \\ &= \sqrt{3} \times 155(2.48 + 4.95) \\ &= \sqrt{3} \times 155 \times 7.43 \\ &= 1990 \text{ volts} \end{aligned}$$

Bus $A$ volts

$$\begin{aligned} &= (\text{source voltage} - \text{voltage drop}) \times (\text{power transformer ratio}) \\ &= (33{,}500 - 1990)\frac{4.160}{34.4 \times 0.975} \\ &= \frac{31{,}510 \times 4.160}{0.975 \times 34.4} = 3910 \text{ volts} \end{aligned}$$



Recalculating the voltage drop assuming 3910 volts on Bus $A$,

$$\text{Overhead line amperes} = \frac{4160}{3910} \times 155 = 165$$

$$v = \sqrt{3} \times 165 \times 7.43 = 2120 \text{ volts}$$

$$\begin{aligned} \text{Bus } A \text{ voltage} &= (33{,}500 - 2120)\frac{4.160}{34.4 \times 0.975} \\ &= \frac{31{,}380 \times 4.160}{34.4 \times 0.975} = 3900 \text{ volts} \end{aligned}$$

This value is assumed to be close enough for practical purposes.

*Bus B Voltage.* From Fig. 4.37,

5-kv cable resistance = 0.1094 ohm
5-kv cable reactance = 0.0712 ohm

$$\begin{aligned} \text{Transformer resistance} &= 1.0\% \text{ on its own base} \\ &= \frac{1.0 \times (4.16)^2 \times 10}{1500} = 0.115 \text{ ohm} \\ \text{Transformer reactance} &= 5.5\% \text{ on its own base} \\ &= \frac{5.5 \times (4.16)^2 \times 10}{1500} \\ &= 0.634 \text{ ohm} \end{aligned}$$

Total ohms resistance = 0.109 + 0.115 = 0.224 ohm
Total ohms reactance = 0.071 + 0.634 = 0.705 ohm

Assuming 450 volts on bus $B$,

$$\text{Bus } B \text{ amperes} = \frac{1300 \text{ kva}}{\sqrt{3} \times 0.450} = 1670$$

$$\text{5-kv cable amperes} = 1670 \times \frac{480}{4160} = 193$$

$$v = \sqrt{3}I(R\cos\theta + X\sin\theta)$$

$\cos\theta = 0.8$, $\sin\theta = 0.6$

$$\begin{aligned} v &= \sqrt{3} \times 193(0.224 \times 0.8 + 0.705 \times 0.6) \\ &= \sqrt{3} \times 193(0.179 + 0.423) \\ &= \sqrt{3} \times 193 \times 0.602 = 201 \text{ volts} \end{aligned}$$

$$\begin{aligned} \text{Bus } B \text{ voltage} &= (\text{bus } A \text{ voltage} - v)\ (\text{transformer ratio}) \\ &= (3900 - 201)\frac{480}{4160} \\ &= \frac{3699 \times 480}{4160} = 426 \text{ volts} \end{aligned}$$



Recalculating $v$ assuming 426 volts on bus $B$ with same load,

$$\text{5-kv cable amperes} = 193 \times \frac{450}{426} = 204$$

$$v = \sqrt{3} \times 204 \times 0.602 = 212 \text{ volts}$$

$$\begin{aligned} \text{Bus } B \text{ voltage} &= (3900 - 212)\frac{480}{4160} \\ &= \frac{3688 \times 480}{4160} = 425 \text{ volts} \end{aligned}$$

Secondary load voltage, assuming 420 volts at load,

$$\text{Load amperes} = \frac{250}{0.420 \times \sqrt{3}} = 344$$

Cable resistance = 0.0072
Cable reactance = 0.0090

$$v = \sqrt{3} \times I(R\cos\theta + X\sin\theta)$$

$\cos\theta = 0.7$, $\sin\theta = 0.714$

$$\begin{aligned} v &= \sqrt{3} \times 344(0.0072 \times 0.7 + 0.0090 \times 0.714) \\ &= \sqrt{3} \times 344(0.00504 + 0.00643) \\ &= \sqrt{3} \times 344 \times 0.01147 \\ &= 6.9 \text{ volts} \end{aligned}$$

Load voltage = 425 − 6.9 = 418.1 volts

Since the most critical feeders with respect to voltage drop have been selected, the calculated load voltages at bus $A$, bus $B$, and at the secondary-load terminals provide sufficient information to analyze the system from the standpoint of voltage drop. Actually, the 480–418 voltage spread at the secondary-load terminals indicates that the system is on the border line and should be stiffened, possibly by using a larger 5-kv feeder cable. However, this is beyond the scope of this problem, which is merely intended to outline the method of determining voltage drop.

To calculate the drop voltage of 33.5kV feeder of 10,000kVA transformer, we will do the miles to km conversions. Therefore, since 2 miles is equivalent to 3218.69m, the values of resistance and reactance of the cable, in Ω/km will be:

$$R = \frac{1{,}97}{3{,}21869} = 0{,}612\Omega/\text{km}$$

$$X = \frac{1{,}52}{3{,}21869} = 0{,}472\Omega/\text{km}$$

Using the spreadsheet PL.EL.SA. CA.04 Feeders - Calculation of Voltage in Load, we have:

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 3,21869 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,612 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,472 |
| | $n$ | Number of Cables per Phase | 1 |
| | $V_F$ | Source Voltage (V) | 33500 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 9000 |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 4160 |
| | $FP_{C_K}$ | Power Factor of the Constant Load | 0,8 |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | |
| | $FP_{C_V}$ | Power Factor of the Variable Load | |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | |
| | $I_{M_{Pn}}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FP_{M_P}$ | Power Factor of the Motor(s) at Starting | |

| | | |
|---|---|---|
| $V_{C_T}$ | *Load voltage considering the defined source voltage* | 32817,85 |

With the voltage of 32,817.85V in the primary of transformer, the voltage in the secondary, considering the use of the 0.975 tap, will be calculated using the spreadsheet PL.EL.SA.AC.01 POWER TRANSFORMERS - Calculation of the Voltage in the Terminals. $Z = 1 + J6 = 6{,}083\%$:

| SYSTEM DATA | | | |
|---|---|---|---|
| 4160 | $V_{P_n}$ | Rated Primary Voltage of Transformer (kV) | 34,4 |
| | $V_{S_n}$ | Rated Secondary Voltage of Transformer (V) | 4160 |
| | $P_{TF_n}$ | Rated Power of Transformer (kVA) | 10000 |
| | $Z_n$ | Rated Impedance of Transformer (%) | 6,083 |
| | $R_n$ | Rated Resistence of Transformer (%) | 1 |
| | $V_P$ | Primary Voltage on Transformer (kV) | 32,81785 |
| | $k$ | Tap Voltage Used of Transformer (pu) | 0,975 |
| 10000 | $Pc_{Kn}$ | Rated Power of Constant Load (kVA) | 9000 |
| | $Vc_{Kn}$ | Rated Voltage of Constant Load (V) | 4160 |
| | $FPc_K$ | Power Factor of Constant Load | 0,8 |
| | $Pc_{Vn}$ | 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) | |
| | $IM_{pn}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FPM_p$ | Power factor of Motor(s) at Starting | |

| | | |
|---|---|---|
| $V_{T_S}$ | *Voltage on Secondary Terminals of Transformer (V)* | 3900,27 |

To calculate the drop voltage in the 4.16kV feeder of the 1,500kVA transformer, we will do the conversions from feet to km. Therefore, as 2000 feet equals 609.6m, the values of resistance and reactance of the cable, in Ω/km will be:

$$R = \frac{0{,}1094}{0{,}6096} = 0{,}1975\Omega/\mathrm{km}$$

$$X = \frac{0{,}0712}{0{,}6096} = 0{,}1168\Omega/\text{km}$$

The voltage on primary of 1500kVA transformer will be 3856.37V:

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,6096 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,1794 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,1168 |
| | $n$ | Number of Cables per Phase | 1 |
| | $V_F$ | Source Voltage (V) | 3900,27 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 1300 |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 480 |
| | $FP_{C_K}$ | Power Factor of the Constant Load | 0,8 |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | |
| | $FP_{C_V}$ | Power Factor of the Variable Load | |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | |
| | $I_{M_{Pn}}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FP_{M_P}$ | Power Factor of the Motor(s) at Starting | |

| | | |
|---|---|---|
| $V_{C_T}$ | *Load voltage considering the defined source voltage* | 3856,37 |

The impedance of the 1500kVA transformer will be:

$$Z = 1 + J5{,}5 = 5{,}59\%$$

The voltage on the secondary of the 1500kVA transformer will be 425.36V:

| SYSTEM DATA | | | |
|---|---|---|---|
| Transformer | $V_{P_n}$ | Rated Primary Voltage of Transformer (kV) | 4,16 |
| | $V_{S_n}$ | Rated Secondary Voltage of Transformer (V) | 480 |
| | $P_{TF_n}$ | Rated Power of Transformer (kVA) | 1500 |
| | $Z_n$ | Rated Impedance of Transformer (%) | 5,59 |
| | $R_n$ | Rated Resistence of Transformer (%) | 1 |
| | $V_P$ | Primary Voltage on Transformer (kV) | 3,85637 |
| | $k$ | Tap Voltage Used of Transformer (pu) | 1 |
| Loads Data | $Pc_{Kn}$ | Rated Power of Constant Load (kVA) | 1300 |
| | $Vc_{Kn}$ | Rated Voltage of Constant Load (V) | 480 |
| | $FPc_K$ | Power Factor of Constant Load | 0,8 |
| | $Pc_{Vn}$ | 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) | |
| | $IM_{pn}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FPM_p$ | Power factor of Motor(s) at Starting | |

| | | |
|---|---|---|
| $V_{T_S}$ | *Voltage on Secondary Terminals of Transformer (V)* | 425,36 |

To calculate the voltage at the 480V load, we will do the conversions from feet to km. Therefore, as 200 feet equals 60.96m, the values of resistance and reactance of the cable, in Ω/km will be:

$$R = \frac{0{,}0072}{0{,}06096} = 0{,}1181\Omega/\text{km}$$

$$X = \frac{0{,}009}{0{,}06096} = 0{,}1476\Omega/\text{km}$$

The voltage on the load will be 418.51V:

| SYSTEM DATA | | | |
|---|---|---|---|
| Source Data | $l$ | Length of Circuit (km) | 0,06096 |
| | $Ra$ | Cable Resistence (Ω/km) | 0,1181 |
| | $Xa$ | Cable Reactance (Ω/km) | 0,1476 |
| | $n$ | Number of Cables per Phase | 1 |
| | $V_F$ | Source Voltage (V) | 425,36 |
| Cargo Data | $P_{C_{Kn}}$ | Rated Power of the Constant Load (kVA) | 250 |
| | $V_{C_{Kn}}$ | Rated Voltage of the Constant Load (V) | 440 |
| | $FP_{C_K}$ | Power Factor of the Constant Load | 0,7 |
| | $P_{C_{Vn}}$ | Rated Power of the Variable Load (kVA) | |
| | $V_{C_{Vn}}$ | Rated Voltage of the Variable Load (V) | |
| | $FP_{C_V}$ | Power Factor of the Variable Load | |
| | $V_{M_{Pn}}$ | Rated Voltage of the Motor(s) (V) | |
| | $I_{M_{Pn}}$ | Starting Current of Motor(s) at Rated Voltage (A) | |
| | $FP_{M_P}$ | Power Factor of the Motor(s) at Starting | |

| | | |
|---|---|---|
| $V_{C_T}$ | *Load voltage considering the defined source voltage* | 418,51 |

That is, the value coincides with the values calculated by the approximate methods and exact value:

| ***Comparison of Results Obtained (V)*** | | | | | |
|---|---|---|---|---|---|
| ***Local*** | ***Solutión*** | | | | |
| | **1** | **2** | **3** | **4** | **Here** |
| ***Bus A*** | 3900 | 3910 | 3925 | 3932 | **3900,27** |
| ***Bus B*** | 425 | 426 | 429 | 432 | **425,36** |
| ***Load*** | 418 | 419 | 422 | 425 | **418,51** |

The values in the table prove the applicability of the spreadsheets to perform the calculations.