# DIESEL GENERATORS SETS

## Calculation of Transient Reactance and Terminals Voltage

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# 1 PURPOSE

The purpose of this *technical information* is to analyze the operating conditions of alternators of diesel generator sets, to calculate the transient reactance that meets the needs of the system, and to calculate the voltage in the alternator terminals during the transit*ory* periods. Based on this analysis, Excel spreadsheets will be prepared to perform the calculations.

# 2 REFERENCE DOCUMENTS

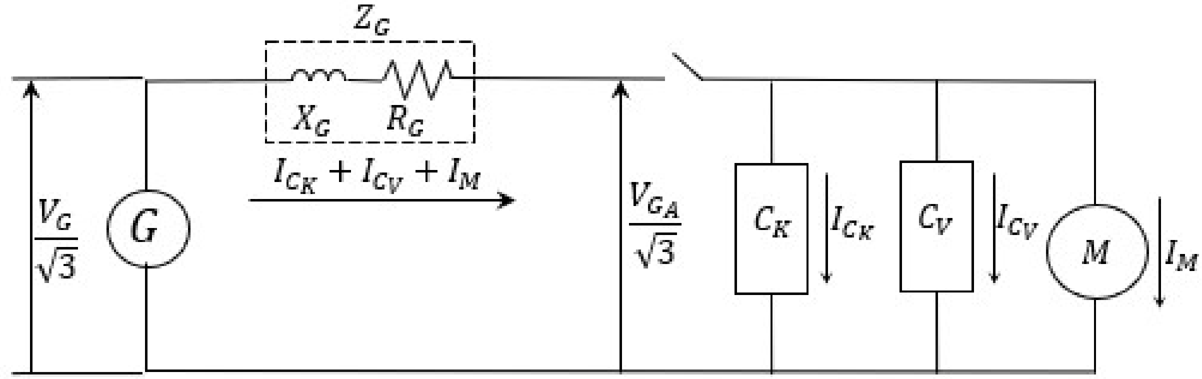
## 2.1 Spreadsheets

PL.EL.SA.CA.02.R1 Diesel Generators Sets - Calculation of Transient Reactance

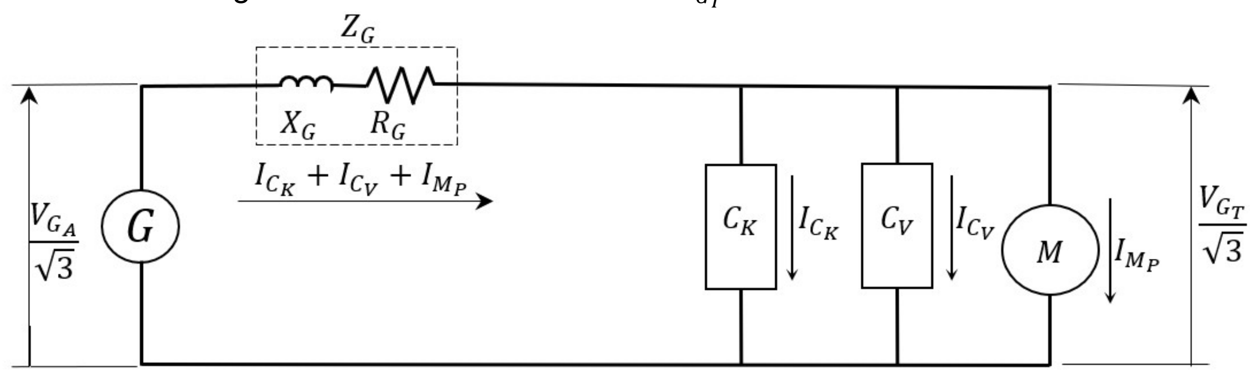
PL.EL.SA.CA.03.R1 Diesel Generators Sets - Calculation of Terminals Voltage

# 3 BASICS CIRCUITS

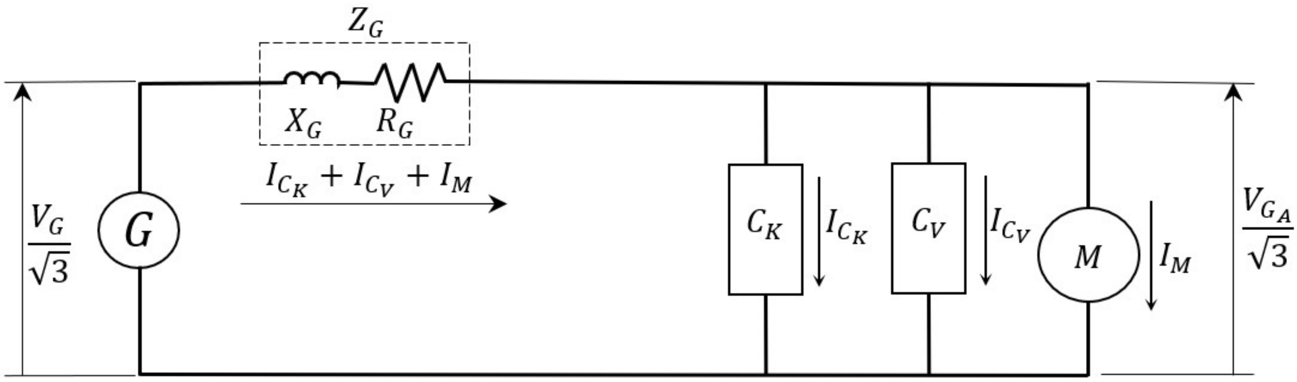
The figure below represents the circuit of an no-load alternator and the various types of loads that are typically found in practice. The loads can be constant power $C_K$, variable power $C_V$ and induction motors $M$. The loads *can* be applied together or individually. Note that in this condition, as the generator is without load, $I_{C_K} + I_{C_V} + I_{M_P} = 0$, there is no voltage drop in the alternator. Therefore, the voltage in the alternator $V_G$ is equal to the adjusted operating voltage of the alternator,$V_{G_A}$.



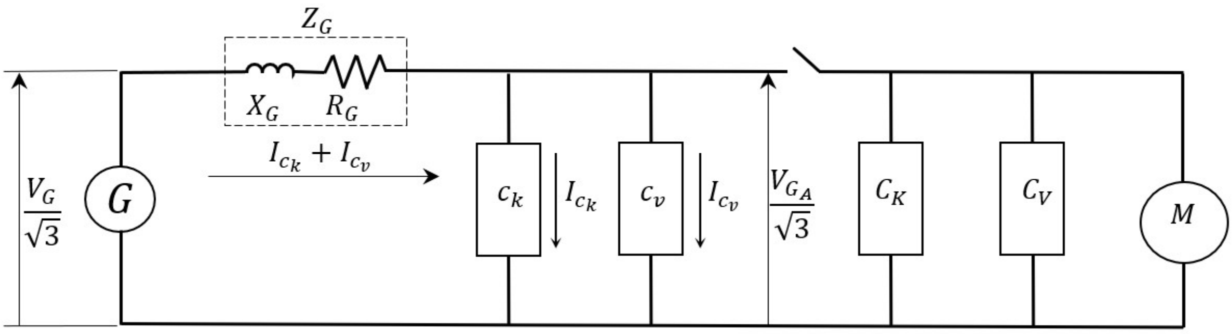

The following figure represents the circuit at the time of application of the load(s), when the voltage in the alternator $V_G$, is equal the setting operating voltage $V_{G_A}$ and, the voltage in the loads is the voltage in the alternator terminals is $V_{G_T}$.



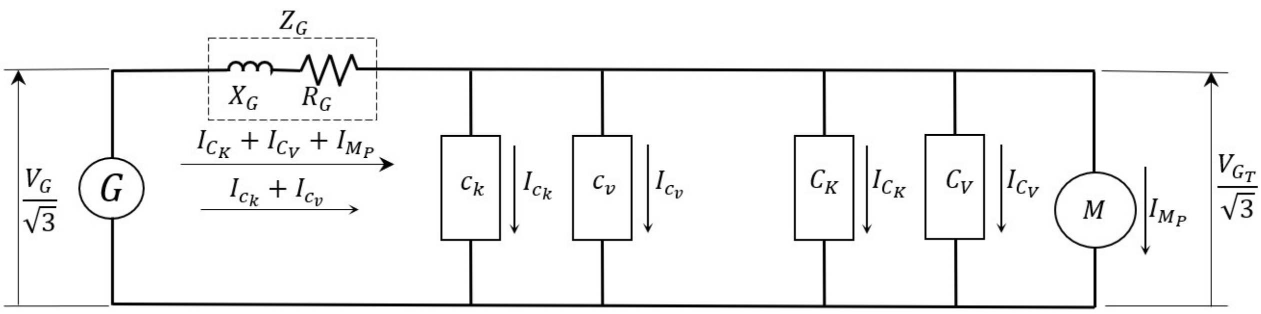

The following figure represents the alternator circuit, with voltage $V_G$, feeding the loads already in normal operation. The momentary voltage $V_{G_T}$ is corrected, by the voltage regulator, to the adjusted operating voltage $V_{G_A}$, supplying the voltage drop in the alternator impedance $Z_G$.




The figure below represents the circuit of an alternator feeding initial loads and the loads that will be applied, together or individually. Note that in this condition the alternator is stabilized at the adjusted operating voltage $V_{G_A}$, in its terminals and at the initial load. So, the alternator voltage $V_G$ will be function of the initial load and alternator impedance. In this condition, the initial load composed of induction motors is included in the constant power load $c_k$ .




The figure below represents the alternator circuit at the time of application of loads $C_K$, $C_V$ and motor(s) $M$, when the alternator was feeding an initial load composed of $c_k$ and $c_v$. The voltage in the alternator terminals, depending on the application of the loads, will pass from $V_{G_A}$ to $V_{G_T}$, which will cause a variation in the current of the loads that were operating.




As the voltage $V_{G_T}$ will be less than $V_{G_A}$, due to the voltage drop in the alternator impedance, the current in the constant load $c_k$ will increase and the current in the variable load $c_v$ will decrease. Therefore, the currents $I_{c_k} + I_{c_v}$ will vary, and the voltage $V_{G_T}$ in the alternator terminals will be a function of the currents $I_{C_K} + I_{C_V} + I_{M_P} + I_{c_k} + I_{c_v}$.

## 4 ALTERNATORS

Alternators are usually 4 poles, depending on the application and rotation of the most used emergency diesel generators, with brushless static excitation system. The rated voltage of the alternators depends on the voltage of the associated system, the power depends on the needs of the loads to be met and the transient reactance depends on the permissible voltage drop in the loads fed.

### 4.1 Characteristics

The characteristics of the alternator that will be used are:

$P_{G_n}$ Rated alternator power (VA)

$V_{G_n}$ Rated alternator voltage (V)

$V_{G_A}$ Adjusted operating voltage (V)

$Z_{G_n}$ Rated impedance of the alternator (%)

$X'_{G_n}$ Rated Transient reactance of the alternator (%)

### 4.2 Voltages

The voltage in the alternator terminals depends on the adjust defined by user, the voltage regulation system has an adjustment range for this purpose. The voltage in the alternator terminals is kept constant during the operation of the diesel generator set, in the adjusted operating voltage $V_{G_A}$, varying only in the transient periods, when the loads are applied or removed. The operating voltage adjusted $V_{G_A}$ is controlled by the voltage regulation system.

The rated voltage of the alternator $V_{G_n}$, is usually equal to the rated voltage of the associated system.

The adjusted operating voltage of the alternator $V_{G_A}$, may be equal to or different from the rated voltage $V_{G_n}$, but within the regulator setting range and voltage limits of the loads.

### 4.3 Impedance of Alternator

The alternator impedance $Z_G$, which will be considered in this document to calculate the voltage drop, will be:

$$Z_G = \frac{{V_{G_n}}^2}{P_{G_n}} \cdot \frac{Z_{G_n}}{100}$$

### 4.4 Resistance of Alternator

The alternator resistance $(R_G)$ will be:

$$R_G = \frac{{V_{G_n}}^2}{P_{G_n}} \cdot \frac{R_{G_n}}{100}$$

### 4.5 Transient Reactance of Alternator

The transient reactance $(\boldsymbol{X'_G})$ of the alternator will be:

$$X'_G = \frac{{V_{G_n}}^2}{P_{G_n}} \cdot \frac{X'_{G_n}}{100}$$

### 4.6 Impedance Angle

The angle of impedance will be:

$$\theta_G = arc\ tan\ \frac{X_G}{R_G}$$

If:

$$R_G = 0$$

$\theta_G = arc\ cos\ 0$

### 4.7 Impedance and Angle

As the impedance of the alternator, for the calculations of this document, will be considered equal to the transient reactance, impedance and angle considered will be:

$$Z_G = X'_G = \frac{{V_{G_n}}^2}{P_{G_n}} \cdot \frac{X'_{G_n}}{100}$$

$\theta_G = arc\ cos\ 0$

Where:

$Z_G$ Impedance of Alternator (Ω)

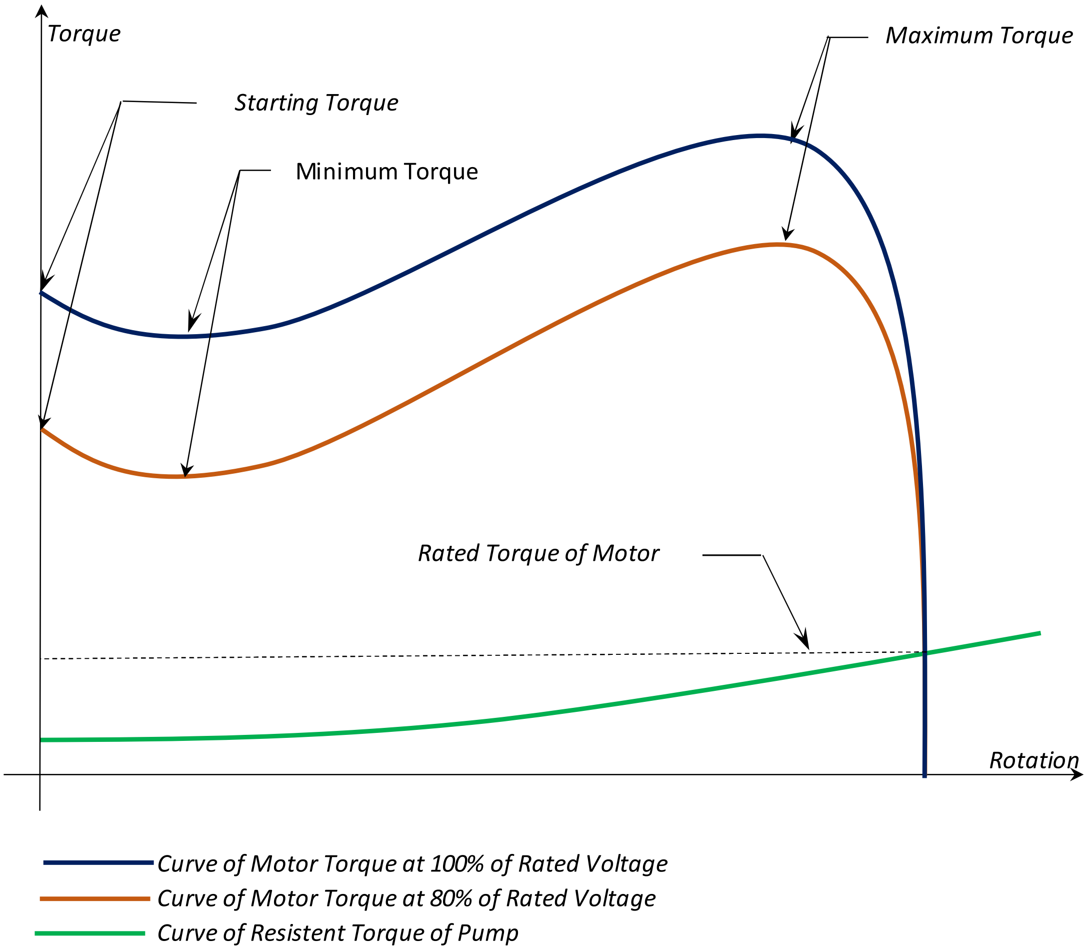
$V_{G_n}$ Rated voltage of alternator (V)

$P_{G_n}$ Rated power of alternator (VA)

$X'_{G_n}$ Rated Transient reactance of the alternator (%)

## 5 CONSTANT POWER LOADS

In constant power loads, the current varies, depending on the voltage, to maintain constant power. In this case are, for example, battery chargers, communication systems and, mainly, induction motors. Induction motors have the characteristic of keeping the rotation practically constant with the voltage variation (see figure below).




$Power = Force\ x\ Velocity$ or $Power = Torque\ x\ Angular\ Velocity$

Note that the motor *torque* varies during engine start and is different for each voltage value, but the *torque* and rotation remain constant during operation. Therefore, as the load (Force or Torque) and speed remain constant, the *p*ower also remains constant, that is, the current variation is inversely proportional to the variation of the voltage.

## 5.1 Power of Constant Load

The power of the constant load in the circuit is given by:

$$P_{C_K} = \frac{{V_{G_T}}^2}{Z_{C_K}}$$

Where:

$P_{C_K}$ - Power of constant load (VA)

$V_{G_T}$ - Voltage in the alternator terminals (V)

$Z_{C_K}$– Impedance of constant load (Ω)

At constant load the power is constant, and equal to the rated power of the load, i.e.:

$$P_{C_{Kn}} = \frac{{V_{C_{Kn}}}^2}{Z_{C_{Kn}}}$$

Where:

$P_{C_{Kn}}$- Rated power of constant load (VA)

$V_{C_{Kn}}$ - Rated voltage of constant load (V)

$Z_{C_{Kn}}$– Rated impedance of constant load (Ω)

## 5.2 Impedance of Constant Load

As the load power is constant:

$$Z_{C_K} = \frac{{V_{G_T}}^2}{P_{C_{Kn}}}$$

## 5.3 Impedance Angle of Constant Load

Because the load power factor is normally an arbitrated value, for example, equal to 0.85,

Where:

$FP_{C_K}$ Power factor of constant load

$$\theta_{C_K} = arc\ cos\left(FP_{C_K}\right)$$

## 5.4 Current of Constant Load

How:

$$\overrightarrow{I_{C_K}} = \frac{\frac{\overrightarrow{V_{G_T}}}{\sqrt{3}}}{\overrightarrow{Z_{C_K}}}$$

$$\overrightarrow{I_{C_K}} = \frac{(\frac{V_{G_T}}{\sqrt{3}}, 0)}{(Z_{C_K}, \theta_{C_K})}$$

$$\overrightarrow{I_{C_K}} = \left(\frac{V_{G_T}}{\sqrt{3}Z_{C_K}}, -\theta_{C_K}\right)$$

But how,

$$Z_{C_K} = \frac{{V_{G_T}}^2}{P_{C_{Kn}}}$$

$$\overrightarrow{I_{C_K}} = \left(\frac{V_{G_T}}{\sqrt{3}\,\frac{{V_{G_T}}^2}{P_{C_{Kn}}}}, -\theta_{C_K}\right)$$

$$\overrightarrow{I_{C_K}} = \left(\frac{P_{C_{Kn}}}{\sqrt{3}V_{G_T}}, -\theta_{C_K}\right)$$

## 6 VARIABLE POWER LOADS

In variable power loads the impedance is a constant value. Therefore, the variation of the voltage causes the current to vary as a function of the impedance of the load. In this case we can consider, for example, loads composed of transformers, reactors, and resistors. In these loads the current is directly proportional to the voltage variation.

### 6.1 Power of Variable Load

In variable power load we have:

$$P_{C_V} = \frac{{V_{G_T}}^2}{Z_{C_V}}$$

Where:

$P_{C_V}$ Power of Variable load (VA)

$V_{G_T}$ Voltage in alternator terminals during transient period (V)

$Z_{C_V}$ impedance of Variable load (Ω)

The rated power of the variable load is:

$$P_{C_{Vn}} = \frac{{V_{C_{Vn}}}^2}{Z_{C_{Vn}}}$$

### 6.2 Impedance of Variable Load

The load is variable because the impedance is constant (for example, resistor), so:

$$Z_{C_V} = Z_{C_{Vn}}$$

$$Z_{C_V} = Z_{C_{Vn}} = \frac{{V_{C_{Vn}}}^2}{P_{C_{Vn}}}$$

$$Z_{C_V} = \frac{{V_{C_{Vn}}}^2}{P_{C_{Vn}}}$$

Where:

$P_{C_{Vn}}$ Rated power of variable load (VA)

$V_{C_{Vn}}$ Rated voltage of variable load (V)

$Z_{C_{Vn}}$ Rated impedance of variable load (Ω)

### 6.3 Variable Load Impedance Angle

The power factor of variable load can be arbitrated or known. For example, if it is a resistor, the power factor is 1.

$$\theta_{C_V} = arc\ cos\left(FP_{C_V}\right)$$

Where:

$FP_{C_V}$ Power factor of variable load

### 6.4 Current of Variable Load

How:

$$I_{C_V} = \frac{\frac{V_{G_T}}{\sqrt{3}}}{Z_{C_V}}$$

But

$$Z_{C_V} = \frac{{V_{C_{Vn}}}^2}{P_{C_{Vn}}}$$

$$I_{C_V} = \frac{\frac{V_{G_T}}{\sqrt{3}}}{\frac{{V_{C_{Vn}}}^2}{P_{C_{Vn}}}}$$

$$I_{C_V} = \frac{P_{C_{Vn}} V_{G_T}}{\sqrt{3}{V_{C_{Vn}}}^2}$$

$$\overrightarrow{I_{C_V}} = \left(\frac{P_{C_{Vn}} V_{G_T}}{\sqrt{3}{V_{C_{Vn}}}^2}, -\theta_{C_V}\right)$$

## 7 STARTING OF MOTORS

In loads composed of starting of motor(s), the impedance of the motor(s), at the starting moment, is fixed value. However, because it is a transient condition of the load, it will be treated differently.

### 7.1 Motor Starting Power

The impedance of motor(s) at starting is a fixed value. Therefore, its behavior is the same as loads with variable power.

$$P_{M_P} = \frac{{V_{G_T}}^2}{Z_{M_P}}$$

Where:

$P_{M_P}$ Power of motor(s) at starting (VA)

$V_{G_T}$ Voltage at alternator terminals during the transitional period (V)

$Z_{M_P}$ Impedance of the motor(s) at starting (Ω)

The rated power of the motor(s) at the starting is:

$$P_{M_{Pn}} = \frac{{V_{M_{Pn}}}^2}{Z_{M_{Pn}}}$$

Where:

$P_{M_{Pn}}$ Rated power of the motor(s) at starting (VA)

$V_{M_{Pn}}$ Rated voltage of the motor(s) (V)

$Z_{M_{Pn}}$ Rated impedance of the motor(s) at starting (Ω)

## 7.2 Impedance of the Motor(s) at the Starting

As the impedance of the motor(s) at the starting is a fixed value:

$$Z_{M_P} = Z_{M_{Pn}}$$

$$Z_{M_P} = Z_{M_{Pn}} = \frac{{V_{M_{Pn}}}^2}{P_{M_{Pn}}}$$

As the rated power of motor(s) at the starting is not a data provided in the manufacturers' tables, we will use the rated starting current, i.e.:

$$P_{M_{Pn}} = \sqrt{3}V_{M_{Pn}}.I_{M_{Pn}}$$

Or:

$$Z_{M_P} = \frac{V_{M_{Pn}}}{\sqrt{3}I_{M_{Pn}}}$$

$$Z_{M_P} = \frac{V_{M_{Pn}}}{\sqrt{3}I_{M_{Pn}}}$$

Where:

$P_{M_{Pn}}$ Rated power of the motor(s) at starting (VA)

$V_{M_{Pn}}$ Rated voltage of the motor(s) (V)

$I_{M_{Pn}}$ Motor(s) starting current at rated voltage (A)

## 7.3 Impedance Angle of Motor(s) at the Starting

The value of power factor of the motor(s) at the starting can be estimated as defined according to the motor data(s). So:

$$\theta_{M_P} = arc\ cos\left(FP_{M_P}\right)$$

Where:

$FP_{M_P}$ Power factor of motor(s) at the starting

## 7.4 Current of Motor(s)at the Starting

How:

$$\overrightarrow{I_{M_P}} = \frac{\frac{\overrightarrow{V_{G_T}}}{\sqrt{3}}}{\overrightarrow{Z_{M_P}}}$$

$$\overrightarrow{I_{M_P}} = \frac{(\frac{V_{G_T}}{\sqrt{3}}, 0)}{(Z_{M_P}, \theta_{M_P})}$$

$$\overrightarrow{I_{M_P}} = \left(\frac{V_{G_T}}{\sqrt{3}Z_{M_P}}, -\theta_{M_P}\right)$$

But how,

$$Z_{M_P} = \frac{V_{M_{Pn}}}{\sqrt{3}I_{M_{Pn}}}$$

$$\overrightarrow{I_{M_P}} = \left(\frac{I_{M_{Pn}}V_{G_T}}{V_{M_{Pn}}}, -\theta_{M_P}\right)$$

## 8 OPERATING CONDITIONS ANALYZED

In the permanent operating regime of the alternators, the voltage regulation system automatically maintains the voltage at the adjusted voltage value $V_{G_A}$, whenever the load is within the limits of the alternator capacity.

During the transitional period of the feeding of a load or set of loads (with or without motor start), voltage variations in the alternator will be considered. The operating conditions that will be analyzed are:

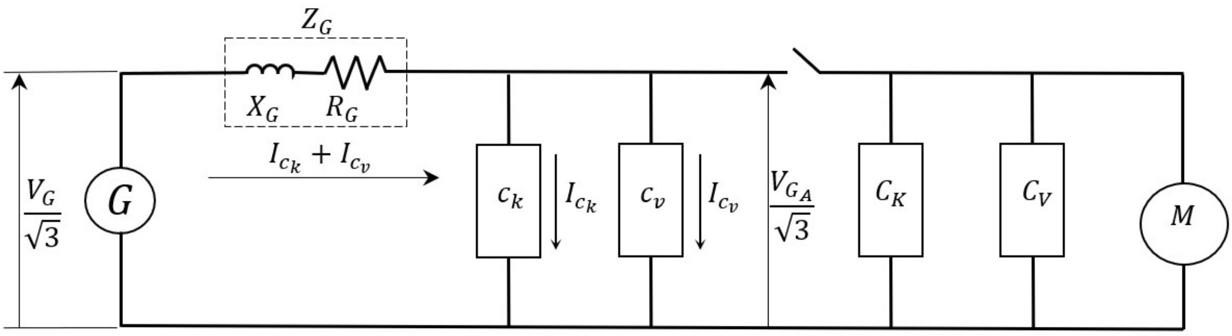
- With the application of the load when the alternator is no-load.

- With the application of the load when the alternator is with an initial load.

The presentation of the calculations is done in detail to allow the perfect understanding of the sequence and concepts adopted, which can be used in the development of other applications. To follow the development user should have only knowledge of complex numbers, in the trigonometric and polar form, besides, of course, electrotechnical.

## 9 VOLTAGE IN ALTERNATOR

The calculation of the voltage in the alternator will be carried out to meet any operating condition and any load condition.




The calculation of the voltage $V_G$ in the alternator will be considered the figure of the circuit above, where:

$V_G$ Voltage in alternator (V)

$V_{G_A}$ Operating voltage adjusted on alternator (V)

$c_k$ Constant initial load (VA)

$c_v$ Variable initial load (VA)

$I_{c_k}$ Current of the constant initial load (A)

$I_{c_v}$ Current of the variable initial load (A)

$Z_G$ Impedance of alternator (Ω)

$R_G$ Resistance of alternator (Ω)

$X_G$ Reactance of alternator (Ω)

$C_K$ Power of constant Load (VA)

$C_V$ Power of variable load (VA)

$M$ Current of Motor(s) (A)

The alternator is feeding a constant load $c_k$ and a variable load $c_v$. In this operating condition, the voltage $V_{G_A}$ on alternator terminals is kept constant by the automatic voltage regulator.

In the case of application of new load(s), constants $C_K$, variables $C_V$, or starting of motor(s) M, the voltage $V_{G_A}$ on alternator terminals will be changed, transitorily, until the voltage regulator corrects the value for the adjusted voltage $V_{G_A}$.

## 9.1 Voltage in Alternator ($V_G$) with Initial Charge

In this condition, loads composed of induction motors sets are included in the constant power load $c_k$.

When the alternator feeds the loads, the voltage in its terminals will be $V_{G_A}$ and will imply that the voltage $V_G$ in the alternator will be given by the formula:

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \frac{\overrightarrow{V_{G_A}}}{\sqrt{3}} + \overrightarrow{Z_G}\left(\overrightarrow{I_{c_k}} + \overrightarrow{I_{c_v}}\right)$$

Whereas:

$$\frac{\overrightarrow{V_{G_A}}}{\sqrt{3}} = \left(\frac{V_{G_A}}{\sqrt{3}} + j0\right)$$

$$\overrightarrow{Z_G} = \left(\frac{{V_{G_n}}^2}{P_{G_n}} \cdot \frac{X'_{G_n}}{100}, arc\,cos\,0\right)$$

$$\overrightarrow{Z_G} = \left(\frac{{V_{G_n}}^2}{P_{G_n}} \cdot \frac{X'_{G_n}}{100}, 90\right)$$

Similar to loads $C_K$ e $C_V$, the same criteria will be adopted, i.e. in polar form:

$$\frac{\overrightarrow{V_{G_A}}}{\sqrt{3}} = \left(\frac{V_{G_A}}{\sqrt{3}}, 0\right)$$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \left(\frac{V_{G_A}}{\sqrt{3}}, 0\right) + \left(\frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}, 90\right)\left(\frac{\left(\frac{V_{G_A}}{\sqrt{3}}, 0\right)}{\left(Z_{c_k}, \theta_{c_k}\right)}\right) + \left(\frac{\left(\frac{V_{G_A}}{\sqrt{3}}, 0\right)}{\left(Z_{c_v}, \theta_{c_v}\right)}\right)$$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \left(\frac{V_{G_A}}{\sqrt{3}}, 0\right) + \left(\frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}, 90\right)\left(\left(\frac{V_{G_A}}{\sqrt{3}\,Z_{c_k}}, -\theta_{c_k}\right) + \left(\frac{V_{G_A}}{\sqrt{3}Z_{c_v}}, -\theta_{c_v}\right)\right)$$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = (\frac{V_{G_A}}{\sqrt{3}}, 0) + \left(\frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}, 90\right)\left(\frac{V_{G_A}}{\sqrt{3}\,Z_{c_k}}, -\theta_{c_k}\right) + \left(\frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}, 90\right)\left(\frac{V_{G_A}}{\sqrt{3}Z_{c_v}}, -\theta_{c_v}\right)$$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = (\frac{V_{G_A}}{\sqrt{3}}, 0) + \left(\frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}\frac{V_{G_A}}{\sqrt{3}\,Z_{c_k}}, (90-\theta_{c_k})\right) + \left(\frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}\frac{V_{G_A}}{\sqrt{3}Z_{c_v}}, (90-\theta_{c_v})\right)$$

In the form of complexes, we have:

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \frac{V_{G_A}}{\sqrt{3}} + j0 + \frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}\frac{V_{G_A}}{\sqrt{3}\,Z_{c_k}}cos(\,90-\theta_{c_k}) +$$
$$+j\frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}\frac{V_{G_A}}{\sqrt{3}\,Z_{c_k}}sen(\,90-\theta_{c_k}) + \frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}\frac{V_{G_A}}{\sqrt{3}Z_{c_v}}cos(\,90-\theta_{c_v}) +$$
$$+j\frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}\frac{V_{G_A}}{\sqrt{3}Z_{c_v}}sen(\,90-\theta_{c_v})$$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \frac{V_{G_A}}{\sqrt{3}} + \frac{{V_{G_n}}^2 X'_{G_n} V_{G_A}}{100\sqrt{3}\,Z_{c_k}P_{G_n}}cos(\,90-\theta_{c_k}) + \frac{{V_{G_n}}^2 X'_{G_n} V_{G_A}}{100\sqrt{3}Z_{c_v}P_{G_n}}cos(\,90-\theta_{c_v}) +$$
$$+j\frac{{V_{G_n}}^2 X'_{G_n} V_{G_A}}{100\sqrt{3}\,Z_{c_k}P_{G_n}}sen(\,90-\theta_{c_k}) + j\frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100}\frac{V_{G_A}}{\sqrt{3}Z_{c_v}}sen(\,90-\theta_m)$$

Replacing $Z_{c_k} = \frac{{V_{G_A}}^2}{P_{c_{kn}}}$ , $Z_{c_v} = \frac{{V_{c_{vn}}}^2}{P_{c_{vn}}}$ and how $cos(90-\theta) = sen\theta$ e $sen(90-\theta) = cos\theta$ have:

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \frac{V_{G_A}}{\sqrt{3}} + \frac{{V_{G_n}}^2 X'_{G_n} V_{G_A}}{100\sqrt{3}\,\frac{{V_{G_A}}^2}{P_{c_{kn}}}P_{G_n}}sen\,\theta_{c_k} + \frac{{V_{G_n}}^2 X'_{G_n} V_{G_A}}{100\sqrt{3}\,\frac{{V_{c_{vn}}}^2}{P_{c_{vn}}}P_{G_n}}sen\theta_{c_v} + j\frac{{V_{G_n}}^2 X'_{G_n} V_{G_A}}{100\sqrt{3}\,\frac{{V_{G_A}}^2}{P_{c_{kn}}}P_{G_n}}cos\,\theta_{c_k} +$$
$$+j\frac{{V_{G_n}}^2}{P_{G_n}}\frac{X'_{G_n}}{100\sqrt{3}}\frac{V_{G_A}}{\frac{{V_{c_{vn}}}^2}{P_{c_{vn}}}}cos\theta_{c_v}$$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \frac{V_{G_A}}{\sqrt{3}} + \frac{{V_{G_n}}^2 X'_{G_n} P_{c_{kn}}}{100\sqrt{3}\,V_{G_A}P_{G_n}}sen\,\theta_{c_k} + \frac{{V_{G_n}}^2 X'_{G_n} V_{G_A} P_{c_{vn}}}{100\sqrt{3}\,{V_{c_{vn}}}^2 P_{G_n}}sen\theta_{c_v} + +j\frac{{V_{G_n}}^2 X'_{G_n} P_{c_{kn}}}{100\sqrt{3}\,V_{G_A}P_{G_n}}cos\,\theta_{c_k} +$$
$$+j\frac{{V_{G_n}}^2 X'_{G_n} V_{G_A} P_{c_{vn}}}{100\sqrt{3}\,{V_{c_{vn}}}^2 P_{G_n}}cos\theta_{c_v}$$

$$\left|\frac{\overrightarrow{V_G}}{\sqrt{3}}\right|^2 = \left[\frac{V_{G_A}}{\sqrt{3}} + \frac{{V_{G_n}}^2 X'_{G_n} P_{c_{kn}}}{100\sqrt{3}\,V_{G_A}P_{G_n}}sen\,\theta_{c_k} + \frac{{V_{G_n}}^2 X'_{G_n} V_{G_A} P_{c_{vn}}}{100\sqrt{3}\,{V_{c_{vn}}}^2 P_{G_n}}sen\theta_{c_v}\right]^2 +$$
$$+\left[\frac{{V_{G_n}}^2 X'_{G_n} P_{c_{kn}}}{100\sqrt{3}\,V_{G_A}P_{G_n}}cos\,\theta_{c_k} + \frac{{V_{G_n}}^2 X'_{G_n} V_{G_A} P_{c_{vn}}}{100\sqrt{3}\,{V_{c_{vn}}}^2 P_{G_n}}cos\theta_{c_v}\right]^2$$

Based on the above formula, you can calculate the voltage of the generation $V_G$, when the alternator feeds an initial load of constant and/or variable power, by the formula:

$$\boldsymbol{V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{P_{c_{kn}}\,sen\,\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A}P_{c_{vn}}sen\theta_{c_v}}{{V_{c_{vn}}}^2}\right)\frac{{V_{G_n}}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \left[\left(\frac{P_{c_{kn}}\cos\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A}P_{c_{vn}}cos\theta_{c_v}}{{V_{c_{vn}}}^2}\right)\frac{{V_{G_n}}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}}$$

## 9.2 Limit of Alternator Voltage $V_G$

The application of loads in an emergency generator diesel set depends on the operator of the equipment, which must comply with the overload limitations established by the manufacturers of the alternator and diesel engine. Therefore, these loads could exceed the rated power of the alternator. If the power of the applied loads exceeds the permitted values, excessive heating of the alternator may occur, and/or a drop in frequency due to reduced speed of the diesel engine and/or loss of voltage regulation control.

For any loads values, even if they are much higher than the rated power of the alternator, if no limit is established for the alternator voltage $\boldsymbol{V_G}$ value, the voltage in the terminals would be kept constant at the adjusted $\boldsymbol{V_{G_A}}$ value, which is not due to the limitations of the voltage regulator and components associated with the group.

To establish the maximum voltage value $\boldsymbol{V_G}$, it will be considered that the alternator continuously provides the rated power**,** with power factor 0.8 in the adjusted voltage $\boldsymbol{V_{G_A}}$.

Considering the formula of the voltage calculation $\boldsymbol{V_G}$, below:

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{P_{C_{kn}}\,sen\,\theta_{C_k}}{V_{G_A}} + \frac{V_{G_A}P_{C_{vn}}sen\theta_{C_v}}{{V_{C_{vn}}}^2}\right)\frac{{V_{G_n}}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \left[\left(\frac{P_{C_{kn}}\cos\theta_{C_k}}{V_{G_A}} + \frac{V_{G_A}P_{C_{vn}}cos\theta_{C_v}}{{V_{C_{vn}}}^2}\right)\frac{{V_{G_n}}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}$$

Where:

$P_{C_{kn}} = P_{G_n}$

$cos\,\theta_{C_k} = 0{,}8$ o which implies that $sen\,\theta_{C_k} = 0{,}6$

$P_{C_{vn}} = 0$

Although the initial load may be composed of constant or variable power loads, the variable load was not considered, as it varies according to the square of the voltage variation. Therefore, if the adjusted voltage value $\mathrm{V_{G_A}}$ is different from the nominal voltage of the alternator, the power requested by the variable load, even if its nominal voltage is equal to that of the alternator, will be different from the rated power of the alternator. For example, if the adjusted voltage value is 110% of the rated voltage of the alternator, the power requested by a variable load, with nominal voltage and power equal to that of the alternator, will be 121% of the nominal power of the variable load, which would compromise the concept adopted here, unless a load with variable power of 82.64% (100/121) of the nominal power of the alternator was considered instead of 100%.

Therefore, the maximum voltage considered for $\boldsymbol{V_G}$ will be given by the formula:

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{0{,}6P_{G_n}}{V_{G_A}} + \frac{0.V_{G_A}sen\theta_{c_v}}{V_{c_{vn}}{}^2}\right)\frac{V_{G_n}{}^2X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \right.$$

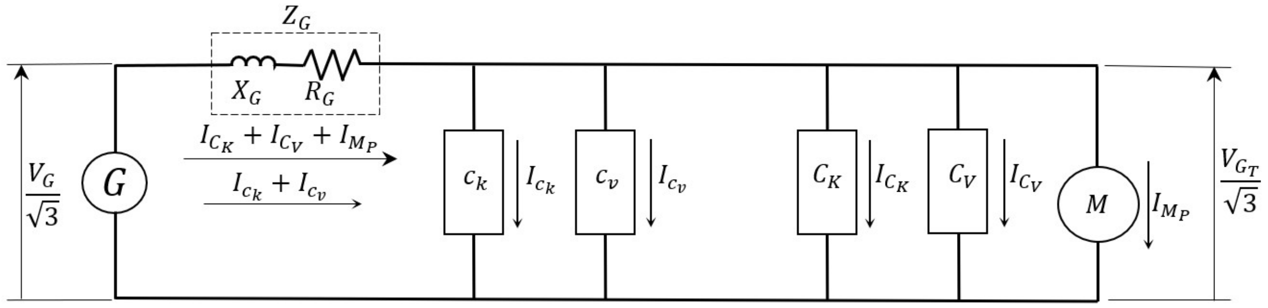
$$\left. + \left[\left(\frac{0{,}8P_{G_n}}{V_{G_A}} + \frac{0.V_{G_A}cos\theta_{c_v}}{V_{c_{vn}}{}^2}\right)\frac{V_{G_n}{}^2X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}$$

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{0{,}6P_{G_n}V_{G_n}{}^2X'_{G_n}}{100\sqrt{3P_{G_n}}V_{G_A}}\right]^2 + \left[\frac{0{,}8P_{G_n}V_{G_n}{}^2X'_{G_n}}{100\sqrt{3\,P_{G_n}}V_{G_A}}\right]^2\right)^{\frac{1}{2}}$$

$$\boldsymbol{V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{0,6V_{G_n}{}^2X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right]^2 + \left[\frac{0,8V_{G_n}{}^2X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right]^2\right)^{\frac{1}{2}}}$$

The voltage value $V_G$ of the alternator will correspond to the value of the adjusted operating voltage $V_{G_A}$.

### 9.3 Voltage in the Alternator Terminals on Load(s) Application




The figure above represents the circuit of the alternator, which was feeding an initial load composed of $c_k$ e $c_v$, at the time of application of the loads $C_K$ $C_V$ and motor $M$,.

The voltage in the alternator terminals, depending on the application of the loads $C_K$ , $C_V$ and motor $M$, will pass from $V_{G_A}$ to $V_{G_T}$, which will cause a variation in currents $I_{c_k}$ e $I_{c_v}$ of the loads that were operating, but the voltage $V_G$ in the alternator will be, temporarily, the same voltage as when was feeding only the initial loads $c_k$ and $c_v$.

Like voltage $V_{G_T}$ will be less than $V_{G_A}$, due to the voltage drop in the alternator impedance, the current at constant load $c_k$ will increase and the current at variable load $c_v$ will decrease. Therefore, the voltage in the terminals of the alternator $V_{G_T}$ will be a function of the currents $I_{C_K} + I_{C_V} + I_{M_P} + I_{c_k} + I_{c_v.}$ and voltage $V_G$.

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \frac{\overrightarrow{V_{G_T}}}{\sqrt{3}} + \overrightarrow{Z_G}\left(\overrightarrow{I_{C_K}} + \overrightarrow{I_{C_V}} + \overrightarrow{I_{M_P}} + \overrightarrow{I_{c_k}} + \overrightarrow{I_{c_v}}\right)$$

Where:

$$\frac{\overrightarrow{V_{G_T}}}{\sqrt{3}} = \left(\frac{V_{G_T}}{\sqrt{3}}, 0\right)$$

$$\overrightarrow{Z_G} = \left(\frac{V_{G_n}{}^2}{P_{G_n}}.\frac{X'_{G_n}}{100}, 90\right)$$

$$\overrightarrow{I_{C_K}} = \left(\frac{P_{C_{Kn}}}{\sqrt{3}V_{G_T}}, -\theta_{C_K}\right)$$

$$\overrightarrow{I_{c_k}} = \left(\frac{P_{c_{kn}}}{\sqrt{3}V_{G_T}}, -\theta_{c_k}\right)$$

$$\overrightarrow{I_{M_P}} = \left(\frac{I_{M_{Pn}}V_{G_T}}{V_{M_{Pn}}}, -\theta_{M_P}\right)$$

$$\overrightarrow{I_{C_V}} = \left(\frac{P_{C_{Vn}}V_{G_T}}{\sqrt{3}{V_{C_{Vn}}}^2}, -\theta_{C_V}\right)$$

$$\overrightarrow{I_{c_v}} = \left(\frac{P_{c_{vn}}V_{G_T}}{\sqrt{3}{V_{c_{vn}}}^2}, -\theta_{c_v}\right)$$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \left(\frac{V_{G_T}}{\sqrt{3}}, 0\right) + \left(\frac{{V_{G_n}}^2}{P_{G_n}}.\frac{X'_{G_n}}{100}, 90\right)\left(\left(\frac{P_{C_{Kn}}}{\sqrt{3}V_{G_T}}, -\theta_{C_K}\right) + \left(\frac{P_{C_{Vn}}V_{G_T}}{\sqrt{3}{V_{C_{Vn}}}^2}, -\theta_{C_V}\right) +\right.$$

$$\left. + \left(\frac{I_{M_{Pn}}V_{G_T}}{V_{M_{Pn}}}, -\theta_{M_P}\right) + \left(\frac{P_{c_{kn}}}{\sqrt{3}V_{G_T}}, -\theta_{c_k}\right) + \left(\frac{P_{c_{vn}}V_{G_T}}{\sqrt{3}{V_{c_{vn}}}^2}, -\theta_{c_v}\right)\right)$$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \left(\frac{V_{G_T}}{\sqrt{3}}, 0\right) + \left(\left(\frac{{V_{G_n}}^2}{P_{G_n}}.\frac{X'_{G_n}}{100}\frac{P_{C_{Kn}}}{\sqrt{3}V_{G_T}}, (90 - \theta_{C_K})\right) +\right.$$

$$+ \left(\frac{{V_{G_n}}^2}{P_{G_n}}.\frac{X'_{G_n}}{100}\frac{P_{C_{Vn}}V_{G_T}}{\sqrt{3}{V_{C_{Vn}}}^2}, (90 - \theta_{C_V})\right) + \left(\frac{{V_{G_n}}^2}{P_{G_n}}.\frac{X'_{G_n}}{100}\frac{I_{M_{Pn}}V_{G_T}}{V_{M_{Pn}}}, (90 - \theta_{M_P})\right) +$$

$$\left. + \left(\frac{{V_{G_n}}^2}{P_{G_n}}.\frac{X'_{G_n}}{100}\frac{P_{c_{kn}}}{\sqrt{3}V_{G_T}}, (90 - \theta_{c_k})\right) + \left(\frac{{V_{G_n}}^2}{P_{G_n}}.\frac{X'_{G_n}}{100}\frac{P_{c_{vn}}V_{G_T}}{\sqrt{3}{V_{c_{vn}}}^2}, (90 - \theta_{c_v})\right)\right)$$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \left(\frac{V_{G_T}}{\sqrt{3}}, 0\right) + \left(\left(\frac{{V_{G_n}}^2}{\sqrt{3}V_{G_T}}.\frac{X'_{G_n}}{100}\frac{P_{C_{Kn}}}{P_{G_n}}, (90 - \theta_{C_K})\right) +\right.$$

$$+ \left(\frac{V_{G_T}{V_{G_n}}^2}{\sqrt{3}{V_{C_{Vn}}}^2}.\frac{X'_{G_n}}{100}\frac{P_{C_{Vn}}}{P_{G_n}}, (90 - \theta_{C_V})\right) + \left(\frac{V_{G_T}{V_{G_n}}^2}{V_{M_{Pn}}}.\frac{X'_{G_n}}{100}\frac{I_{M_{Pn}}}{P_{G_n}}, (90 - \theta_{M_P})\right) +$$

$$\left. + \left(\frac{{V_{G_n}}^2}{\sqrt{3}V_{G_T}}.\frac{X'_{G_n}}{100}\frac{P_{c_{kn}}}{P_{G_n}}, (90 - \theta_{c_k})\right) + \left(\frac{V_{G_T}{V_{G_n}}^2}{\sqrt{3}{V_{c_{vn}}}^2}.\frac{X'_{G_n}}{100}\frac{P_{c_{vn}}}{P_{G_n}}, (90 - \theta_{c_v})\right)\right)$$

In the form of complexes, we have:

$$\frac{\overrightarrow{V_G}}{\sqrt{3}} = \frac{V_{G_T}}{\sqrt{3}} + \frac{{V_{G_n}}^2}{\sqrt{3}V_{G_T}}.\frac{X'_{G_n}}{100}\frac{P_{C_{Kn}}}{P_{G_n}}cos(90 - \theta_{C_K}) + j\frac{{V_{G_n}}^2}{\sqrt{3}V_{G_T}}.\frac{X'_{G_n}}{100}\frac{P_{C_{Kn}}}{P_{G_n}}sen(90 - \theta_{C_K}) +$$

$$+ \frac{V_{G_T}{V_{G_n}}^2}{\sqrt{3}{V_{C_{Vn}}}^2}.\frac{X'_{G_n}}{100}\frac{P_{C_{Vn}}}{P_{G_n}}cos(90 - \theta_{C_V}) + j\frac{V_{G_T}{V_{G_n}}^2}{\sqrt{3}{V_{C_{Vn}}}^2}.\frac{X'_{G_n}}{100}\frac{P_{C_{Vn}}}{P_{G_n}}sen(90 - \theta_{C_V}) +$$

$$+\frac{V_{G_T}V_{G_n}{}^2}{V_{MPn}}\cdot\frac{X'_{G_n}}{100}\frac{I_{MPn}}{P_{G_n}}cos(90-\theta_{MP})+j\frac{V_{G_T}V_{G_n}{}^2}{V_{MPn}}\cdot\frac{X'_{G_n}}{100}\frac{I_{MPn}}{P_{G_n}}sen(90-\theta_{MP})+$$
$$+\frac{V_{G_n}{}^2}{\sqrt{3}V_{G_T}}\cdot\frac{X'_{G_n}}{100}\frac{P_{C_{kn}}}{P_{G_n}}cos(90-\theta_{c_k})+j\frac{V_{G_n}{}^2}{\sqrt{3}V_{G_T}}\cdot\frac{X'_{G_n}}{100}\frac{P_{C_{kn}}}{P_{G_n}}sen(90-\theta_{c_k})+$$
$$+\frac{V_{G_T}V_{G_n}{}^2}{\sqrt{3}V_{c_{vn}}{}^2}\cdot\frac{X'_{G_n}}{100}\frac{P_{c_{vn}}}{P_{G_n}}cos(90-\theta_{c_v})+j\frac{V_{G_T}V_{G_n}{}^2}{\sqrt{3}V_{c_{vn}}{}^2}\cdot\frac{X'_{G_n}}{100}\frac{P_{c_{vn}}}{P_{G_n}}sen(90-\theta_{c_v})$$

How $cos(90-\theta)=sen\theta$ e $sen(90-\theta)=cos\theta$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}}=\frac{V_{G_T}}{\sqrt{3}}+\frac{V_{G_n}{}^2}{\sqrt{3}V_{G_T}}\cdot\frac{X'_{G_n}}{100}\frac{P_{C_{Kn}}}{P_{G_n}}sen\theta_{C_K}+j\frac{V_{G_n}{}^2}{\sqrt{3}V_{G_T}}\cdot\frac{X'_{G_n}}{100}\frac{P_{C_{Kn}}}{P_{G_n}}cos\theta_{C_K}+\frac{V_{G_T}V_{G_n}{}^2}{\sqrt{3}V_{C_{Vn}}{}^2}\cdot\frac{X'_{G_n}}{100}\frac{P_{C_{Vn}}}{P_{G_n}}sen\theta_{C_V}$$
$$+j\frac{V_{G_T}V_{G_n}{}^2}{\sqrt{3}V_{C_{Vn}}{}^2}\cdot\frac{X'_{G_n}}{100}\frac{P_{C_{Vn}}}{P_{G_n}}cos\theta_{C_V}+\frac{V_{G_T}V_{G_n}{}^2}{V_{MPn}}\cdot\frac{X'_{G_n}}{100}\frac{I_{MPn}}{P_{G_n}}sen\theta_{MP}+j\frac{V_{G_T}V_{G_n}{}^2}{V_{MPn}}\cdot\frac{X'_{G_n}}{100}\frac{I_{MPn}}{P_{G_n}}cos\theta_{MP}+$$
$$+\frac{V_{G_n}{}^2}{\sqrt{3}V_{G_T}}\cdot\frac{X'_{G_n}}{100}\frac{P_{c_{kn}}}{P_{G_n}}sen\theta_{c_k}+j\frac{V_{G_n}{}^2}{\sqrt{3}V_{G_T}}\cdot\frac{X'_{G_n}}{100}\frac{P_{c_{kn}}}{P_{G_n}}cos\theta_{c_k}+\frac{V_{G_T}V_{G_n}{}^2}{\sqrt{3}V_{c_{vn}}{}^2}\cdot\frac{X'_{G_n}}{100}\frac{P_{c_{vn}}}{P_{G_n}}sen\theta_{c_v}+$$
$$+j\frac{V_{G_T}V_{G_n}{}^2}{\sqrt{3}V_{c_{vn}}{}^2}\cdot\frac{X'_{G_n}}{100}\frac{P_{c_{vn}}}{P_{G_n}}cos\theta_{c_v}$$

$$\frac{\overrightarrow{V_G}}{\sqrt{3}}=\left[\frac{V_{G_T}}{\sqrt{3}}+\frac{V_{G_n}{}^2}{\sqrt{3}V_{G_T}}\cdot\frac{X'_{G_n}}{100}\frac{P_{C_{Kn}}}{P_{G_n}}sen\theta_{C_K}+\frac{V_{G_T}V_{G_n}{}^2}{\sqrt{3}V_{C_{Vn}}{}^2}\cdot\frac{X'_{G_n}}{100}\frac{P_{C_{Vn}}}{P_{G_n}}sen\theta_{C_V}+\right.$$
$$\left.+\frac{V_{G_T}V_{G_n}{}^2}{V_{MPn}}\cdot\frac{X'_{G_n}}{100}\frac{I_{MPn}}{P_{G_n}}sen\theta_{MP}+\frac{V_{G_n}{}^2}{\sqrt{3}V_{G_T}}\cdot\frac{X'_{G_n}}{100}\frac{P_{c_{kn}}}{P_{G_n}}sen\theta_{c_k}+\frac{V_{G_T}V_{G_n}{}^2}{\sqrt{3}V_{c_{vn}}{}^2}\cdot\frac{X'_{G_n}}{100}\frac{P_{c_{vn}}}{P_{G_n}}sen\theta_{c_v}\right]+$$
$$+j\left[\frac{V_{G_n}{}^2}{\sqrt{3}V_{G_T}}\cdot\frac{X'_{G_n}}{100}\frac{P_{C_{Kn}}}{P_{G_n}}cos\theta_{C_K}+\frac{V_{G_T}V_{G_n}{}^2}{\sqrt{3}V_{C_{Vn}}{}^2}\cdot\frac{X'_{G_n}}{100}\frac{P_{C_{Vn}}}{P_{G_n}}cos\theta_{C_V}+\frac{V_{G_T}V_{G_n}{}^2}{V_{MPn}}\cdot\frac{X'_{G_n}}{100}\frac{I_{MPn}}{P_{G_n}}cos\theta_{MP}+\right.$$
$$\left.+\frac{V_{G_n}{}^2}{\sqrt{3}V_{G_T}}\cdot\frac{X'_{G_n}}{100}\frac{P_{c_{kn}}}{P_{G_n}}cos\theta_{c_k}+\frac{V_{G_T}V_{G_n}{}^2}{\sqrt{3}V_{c_{vn}}{}^2}\cdot\frac{X'_{G_n}}{100}\frac{P_{c_{vn}}}{P_{G_n}}cos\theta_{c_v}\right]$$

$$\left|\frac{\overrightarrow{V_G}}{\sqrt{3}}\right|^2=\left[\frac{V_{G_T}}{\sqrt{3}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Kn}}sen\theta_{C_K}}{100\sqrt{3}V_{G_T}P_{G_n}}+\frac{V_{G_T}V_{G_n}{}^2X'_{G_n}P_{C_{Vn}}sen\theta_{C_V}}{100\sqrt{3}V_{C_{Vn}}{}^2P_{G_n}}+\frac{V_{G_T}V_{G_n}{}^2X'_{G_n}I_{MPn}sen\theta_{MP}}{100V_{MPn}P_{G_n}}+\right.$$
$$\left.+\frac{V_{G_n}{}^2X'_{G_n}P_{c_{kn}}sen\theta_{c_k}}{100\sqrt{3}V_{G_T}P_{G_n}}+\frac{V_{G_T}V_{G_n}{}^2X'_{G_n}P_{c_{vn}}sen\theta_{c_v}}{100\sqrt{3}V_{c_{vn}}{}^2P_{G_n}}\right]^2+\left[\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Kn}}cos\theta_{C_K}}{100\sqrt{3}V_{G_T}P_{G_n}}+\frac{V_{G_n}{}^2X'_{G_n}P_{c_{kn}}cos\theta_{c_k}}{100\sqrt{3}V_{G_T}P_{G_n}}\right.$$
$$\left.+\frac{V_{G_T}V_{G_n}{}^2X'_{G_n}P_{C_{Vn}}cos\theta_{C_V}}{100\sqrt{3}V_{C_{Vn}}{}^2P_{G_n}}+\frac{V_{G_T}V_{G_n}{}^2X'_{G_n}I_{MPn}cos\theta_{MP}}{100V_{MPn}P_{G_n}}+\frac{V_{G_T}V_{G_n}{}^2X'_{G_n}P_{c_{vn}}cos\theta_{c_v}}{100\sqrt{3}V_{c_{vn}}{}^2P_{G_n}}\right]^2$$

$$\left[\frac{V_{G_T}}{\sqrt{3}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Kn}}sen\theta_{C_K}}{100\sqrt{3}V_{G_T}P_{G_n}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Vn}}V_{G_T}sen\theta_{C_V}}{100\sqrt{3}V_{C_{Vn}}{}^2P_{G_n}}+\frac{V_{G_n}{}^2X'_{G_n}I_{MPn}V_{G_T}sen\theta_{MP}}{100P_{G_n}V_{MPn}}+\right.$$
$$\left.+\frac{V_{G_n}{}^2X'_{G_n}P_{c_{kn}}sen\theta_{c_k}}{100\sqrt{3}V_{G_T}P_{G_n}}+\frac{V_{G_n}{}^2X'_{G_n}P_{c_{vn}}V_{G_T}sen\theta_{c_v}}{100\sqrt{3}P_{G_n}V_{c_{vn}}{}^2}\right]^2+\left[\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Kn}}cos\theta_{C_K}}{100\sqrt{3}V_{G_T}P_{G_n}}+\right.$$

$$+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Vn}}V_{G_T}cos\theta_{C_V}}{100\sqrt{3}V_{C_{Vn}}{}^2P_{G_n}}+\frac{V_{G_n}{}^2X'_{G_n}I_{M_{Pn}}V_{G_T}cos\theta_{M_P}}{100P_{G_n}V_{M_{Pn}}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{kn}}cos\theta_{C_k}}{100\sqrt{3}V_{G_T}P_{G_n}}+$$
$$+\left.\frac{V_{G_n}{}^2X'_{G_n}P_{C_{vn}}V_{G_T}cos\theta_{C_v}}{100\sqrt{3}P_{G_n}V_{C_{vn}}{}^2}\right]^2-\frac{V_G{}^2}{3}=0$$

$$\left[\frac{V_{G_T}}{\sqrt{3}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Vn}}V_{G_T}sen\theta_{C_V}}{100\sqrt{3}V_{C_{Vn}}{}^2P_{G_n}}+\frac{V_{G_n}{}^2X'_{G_n}I_{M_{Pn}}V_{G_T}sen\theta_{M_P}}{100P_{G_n}V_{M_{Pn}}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{vn}}V_{G_T}sen\theta_{C_v}}{100\sqrt{3}P_{G_n}V_{C_{vn}}{}^2}+\right.$$
$$+\left.\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Kn}}sen\theta_{C_K}}{100\sqrt{3}V_{G_T}P_{G_n}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{kn}}sen\theta_{C_k}}{100\sqrt{3}V_{G_T}P_{G_n}}\right]^2+\left[\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Vn}}V_{G_T}cos\theta_{C_V}}{100\sqrt{3}V_{C_{Vn}}{}^2P_{G_n}}+\right.$$
$$+\frac{V_{G_n}{}^2X'_{G_n}I_{M_{Pn}}V_{G_T}cos\theta_{M_P}}{100P_{G_n}V_{M_{Pn}}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{vn}}V_{G_T}cos\theta_{C_v}}{100\sqrt{3}P_{G_n}V_{C_{vn}}{}^2}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Kn}}cos\theta_{C_K}}{100\sqrt{3}V_{G_T}P_{G_n}}+$$
$$+\left.\frac{V_{G_n}{}^2X'_{G_n}P_{C_{kn}}cos\theta_{C_k}}{100\sqrt{3}V_{G_T}P_{G_n}}\right]^2-\frac{V_G{}^2}{3}=0$$

$$\left[\left(\frac{1}{\sqrt{3}}+\left(\frac{P_{C_{Vn}}sen\theta_{C_V}}{\sqrt{3}V_{C_{Vn}}{}^2P_{G_n}}+\frac{I_{M_{Pn}}sen\theta_{M_P}}{P_{G_n}V_{M_{Pn}}}+\frac{P_{C_{vn}}sen\theta_{C_v}}{\sqrt{3}P_{G_n}V_{C_{vn}}{}^2}\right)\frac{V_{G_n}{}^2X'_{G_n}}{100}\right)V_{G_T}+\left(\frac{P_{C_{Kn}}sen\theta_{C_K}}{P_{G_n}}+\right.\right.$$
$$+\left.\left.\frac{P_{C_{kn}}sen\theta_{C_k}}{P_{G_n}}\right)\frac{V_{G_n}{}^2X'_{G_n}}{100\sqrt{3}}\frac{1}{V_{G_T}}\right]^2+\left[\left(\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Vn}}cos\theta_{C_V}}{100\sqrt{3}V_{C_{Vn}}{}^2P_{G_n}}+\frac{I_{M_{Pn}}cos\theta_{M_P}}{P_{G_n}V_{M_{Pn}}}+\frac{P_{C_{vn}}cos\theta_{C_v}}{\sqrt{3}P_{G_n}V_{C_{vn}}{}^2}\right)+\right.$$
$$+\left.\frac{V_{G_n}{}^2X'_{G_n}}{100}V_{G_T}+\left(\frac{P_{C_{Kn}}cos\theta_{C_K}}{P_{G_n}}+\frac{P_{C_{kn}}cos\theta_{C_k}}{P_{G_n}}\right)\frac{V_{G_n}{}^2X'_{G_n}}{100\sqrt{3}}\frac{1}{V_{G_T}}\right]^2-\frac{V_G{}^2}{3}=0$$

If we consider that:

$$x=V_{G_T}$$

$$a_1=\frac{1}{\sqrt{3}}+\left(\frac{P_{C_{Vn}}sen\theta_{C_V}}{\sqrt{3}V_{C_{Vn}}{}^2P_{G_n}}+\frac{I_{M_{Pn}}sen\theta_{M_P}}{P_{G_n}V_{M_{Pn}}}+\frac{P_{C_{vn}}sen\theta_{C_v}}{\sqrt{3}P_{G_n}V_{C_{vn}}{}^2}\right)\frac{V_{G_n}{}^2X'_{G_n}}{100}$$

$$b_1=\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Kn}}sen\theta_{C_K}}{100\sqrt{3}P_{G_n}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{kn}}sen\theta_{C_k}}{100\sqrt{3}P_{G_n}}$$

$$c_1=\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Vn}}cos\theta_{C_V}}{100\sqrt{3}V_{C_{Vn}}{}^2P_{G_n}}+\frac{V_{G_n}{}^2X'_{G_n}I_{M_{Pn}}cos\theta_{M_P}}{100P_{G_n}V_{M_{Pn}}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{vn}}cos\theta_{C_v}}{100\sqrt{3}P_{G_n}V_{C_{vn}}{}^2}$$

$$d_1=\frac{V_{G_n}{}^2X'_{G_n}P_{C_{Kn}}cos\theta_{C_K}}{100\sqrt{3}P_{G_n}}+\frac{V_{G_n}{}^2X'_{G_n}P_{C_{kn}}cos\theta_{C_k}}{100\sqrt{3}P_{G_n}}$$

$$e_1=-\frac{V_G{}^2}{3}$$

We can write the featured equation as:

$$\left(a_1x+\frac{b_1}{x}\right)^2+\left(c_1x+\frac{d_1}{x}\right)^2+e_1=0$$

$$\left(a_1{}^2x^2 + 2a_1x\frac{b_1}{x} + \left(\frac{b_1}{x}\right)^2\right) + \left(c_1{}^2x^2 + 2c_1x\frac{d_1}{x} + \left(\frac{d_1}{x}\right)^2\right) + e_1 = 0$$

$$a_1{}^2x^2 + 2a_1b_1 + \frac{b_1{}^2}{x^2} + c_1{}^2x^2 + 2c_1d_1 + \frac{d_1{}^2}{x^2} + e_1 = 0$$

$$a_1{}^2x^2 + c_1{}^2x^2 + 2a_1b_1 + 2c_1d_1 + \frac{b_1{}^2 + d_1{}^2}{x^2} + e_1 = 0$$

$$(a_1{}^2 + c_1{}^2)x^2 + 2a_1b_1 + 2c_1d_1 + e_1 + \frac{b_1{}^2 + d_1{}^2}{x^2} = 0$$

Multiplying by $x^2$ we have:

$$(a_1{}^2 + c_1{}^2)x^4 + (2a_1b_1 + 2c_1d_1 + e_1)x^2 + b_1{}^2 + d_1{}^2 = 0$$

The solution of the above equation will be the real and positive root of the equation below;

$$ax^4 + cx^2 + e = 0$$

Onde:

$$a = a_1{}^2 + c_1{}^2$$

$$c = 2a_1b_1 + 2c_1d_1 + e_1$$

$$e = b_1{}^2 + d_1{}^2$$

$$x^2 = V_{G_T}{}^2 = \frac{-c + \sqrt{c^2 - 4ae}}{2a}$$

$$\boldsymbol{V_{G_T} = \sqrt{\frac{-c + \sqrt{c^2 - 4ae}}{2a}}}$$

The above formula provides the voltage value at the alternator terminals, not only when it is with permanent, constant and/or variable load, but also when it is with an initial load and applies a load composed of other loads (constants and/or variables) and motor start(es), together or individually.

## 10 TRANSIENT REACTANCE OF THE ALTERNATOR

To calculate the transient reactance of the alternator, we will use the formulas for calculating the stresses in the alternator, without and with initial load.

In the Voltage Calculation in the Alternator, only initial load, we saw that:

$$\left|\frac{\overrightarrow{V_G}}{\sqrt{3}}\right|^2 = \left[\frac{V_{G_A}}{\sqrt{3}} + \frac{V_{G_n}{}^2 X'_{G_n} P_{c_{kn}}}{100\sqrt{3}\,V_{G_A} P_{G_n}} sen\,\theta_{c_k} + \frac{V_{G_n}{}^2 X'_{G_n} V_{G_A} P_{c_{vn}}}{100\sqrt{3}\,V_{c_{vn}}{}^2 P_{G_n}} sen\theta_{c_v}\right]^2 + \left[\frac{V_{G_n}{}^2 X'_{G_n} P_{c_{kn}}}{100\sqrt{3}\,V_{G_A} P_{G_n}} \cos\theta_{c_k} + \right.$$
$$\left. + \frac{V_{G_n}{}^2 X'_{G_n} V_{G_A} P_{c_{vn}}}{100\sqrt{3}\,V_{c_{vn}}{}^2 P_{G_n}} \cos\theta_{c_v}\right]^2$$

In the Voltage Calculation in the Alternator, only with initial load and application of loads, we saw that:

$$\left|\frac{\overrightarrow{V_G}}{\sqrt{3}}\right|^2 = \left[\frac{V_{G_T}}{\sqrt{3}} + \frac{{V_{G_n}}^2 X'_{G_n} P_{C_{Kn}} sen\theta_{C_K}}{100\sqrt{3} V_{G_T} P_{G_n}} + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} P_{C_{Vn}} sen\theta_{C_V}}{100\sqrt{3} {V_{C_{Vn}}}^2 P_{G_n}} + \right.$$

$$\left. + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} I_{M_{Pn}} sen\theta_{M_P}}{100 V_{M_{Pn}} P_{G_n}} + \frac{{V_{G_n}}^2 X'_{G_n} P_{c_{kn}} sen\theta_{c_k}}{100\sqrt{3} V_{G_T} P_{G_n}} + + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} P_{c_{vn}} sen\theta_{c_v}}{100\sqrt{3} {V_{c_{vn}}}^2 P_{G_n}}\right]^2 +$$

$$+ \left[\frac{{V_{G_n}}^2 X'_{G_n} P_{C_{Kn}} cos\theta_{C_K}}{100\sqrt{3} V_{G_T} P_{G_n}} + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} P_{C_{Vn}} cos\theta_{C_V}}{100\sqrt{3} {V_{C_{Vn}}}^2 P_{G_n}} + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} I_{M_{Pn}} cos\theta_{M_P}}{100 V_{M_{Pn}} P_{G_n}} + \right.$$

$$\left. + \frac{{V_{G_n}}^2 X'_{G_n} P_{c_{kn}} cos\theta_{c_k}}{100\sqrt{3} V_{G_T} P_{G_n}} + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} P_{c_{vn}} cos\theta_{c_v}}{100\sqrt{3} {V_{c_{vn}}}^2 P_{G_n}}\right]^2$$

With the alternator having an initial load, the voltage $V_G$ of alternator does not change instantly when applying new load(s). Therefore, as if the voltage regulator did not exist, the alternator voltage $V_G$, at moment of application of the new load(s), will be the same voltage that the alternator had when it was feeding only the initial loads. The voltage drop in the alternator terminals will be a consequence of the variation of the current, in the impedance of the alternator, due to the application of the new load(s) load(s) and variation of the current in the initial loads. After applying the new load(s), the voltage $V_G$ the alternator will be adjusted by the automatic voltage regulator so that the voltage at the alternator terminals corresponds to the adjusted voltage value $V_{G_A}$

From the above, equaling the values of $\left|\frac{\overrightarrow{V_G}}{\sqrt{3}}\right|^2$ of the two equations highlighted above, we have:

$$\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{{V_{G_n}}^2 X'_{G_n} P_{c_{kn}}}{100\sqrt{3}\, V_{G_A} P_{G_n}} sen\,\theta_{c_k} + \frac{{V_{G_n}}^2 X'_{G_n} V_{G_A} P_{c_{vn}}}{100\sqrt{3}\, {V_{c_{vn}}}^2 P_{G_n}} sen\theta_{c_v}\right]^2 + \left[\frac{{V_{G_n}}^2 X'_{G_n} P_{c_{kn}}}{100\sqrt{3}\, V_{G_A} P_{G_n}} cos\,\theta_{c_k} + \right.$$

$$\left. + \frac{{V_{G_n}}^2 X'_{G_n} V_{G_A} P_{c_{vn}}}{100\sqrt{3}\, {V_{c_{vn}}}^2 P_{G_n}} cos\theta_{c_v}\right]^2 = \left[\frac{V_{G_T}}{\sqrt{3}} + \frac{{V_{G_n}}^2 X'_{G_n} P_{C_{Kn}} sen\theta_{C_K}}{100\sqrt{3} V_{G_T} P_{G_n}} + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} P_{C_{Vn}} sen\theta_{C_V}}{100\sqrt{3} {V_{C_{Vn}}}^2 P_{G_n}} + \right.$$

$$\left. + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} I_{M_{Pn}} sen\theta_{M_P}}{100 V_{M_{Pn}} P_{G_n}} + \frac{{V_{G_n}}^2 X'_{G_n} P_{c_{kn}} sen\theta_{c_k}}{100\sqrt{3} V_{G_T} P_{G_n}} + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} P_{c_{vn}} sen\theta_{c_v}}{100\sqrt{3} {V_{c_{vn}}}^2 P_{G_n}}\right]^2 +$$

$$+ \left[\frac{{V_{G_n}}^2 X'_{G_n} P_{C_{Kn}} cos\theta_{C_K}}{100\sqrt{3} V_{G_T} P_{G_n}} + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} P_{C_{Vn}} cos\theta_{C_V}}{100\sqrt{3} {V_{C_{Vn}}}^2 P_{G_n}} + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} I_{M_{Pn}} cos\theta_{M_P}}{100 V_{M_{Pn}} P_{G_n}} + \right.$$

$$\left. + \frac{{V_{G_n}}^2 X'_{G_n} P_{c_{kn}} cos\theta_{c_k}}{100\sqrt{3} V_{G_T} P_{G_n}} + \frac{V_{G_T} {V_{G_n}}^2 X'_{G_n} P_{c_{vn}} cos\theta_{c_v}}{100\sqrt{3} {V_{c_{vn}}}^2 P_{G_n}}\right]^2$$

$$\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{P_{c_{kn}}\, sen\,\theta_{c_k}}{V_{G_A}} \frac{{V_{G_n}}^2}{100\sqrt{3}\, P_{G_n}} X'_{G_n} + \frac{V_{G_A} P_{c_{vn}} sen\theta_{c_v}}{{V_{c_{vn}}}^2} \frac{{V_{G_n}}^2}{100\sqrt{3}\, P_{G_n}} X'_{G_n}\right]^2 +$$

$$+ \left[\frac{P_{c_{kn}}\, cos\,\theta_{c_k}}{V_{G_A}} \frac{{V_{G_n}}^2}{100\sqrt{3}\, P_{G_n}} X'_{G_n} + \frac{V_{G_A} P_{c_{vn}} cos\theta_{c_v}}{{V_{c_{vn}}}^2} \frac{{V_{G_n}}^2}{100\sqrt{3}\, P_{G_n}} X'_{G_n}\right]^2 =$$

$$= \left[\frac{V_{G_T}}{\sqrt{3}} + \frac{P_{C_{Kn}} sen\theta_{C_K}}{\sqrt{3} V_{G_T}} \frac{{V_{G_n}}^2}{100 P_{G_n}} X'_{G_n} + \frac{V_{G_T} P_{C_{Vn}} sen\theta_{C_V}}{\sqrt{3} {V_{C_{Vn}}}^2} \frac{{V_{G_n}}^2}{100 P_{G_n}} X'_{G_n} + \right.$$

$$+\frac{V_{G_T}I_{M_{Pn}}sen\theta_{M_P}}{V_{M_{Pn}}}\frac{{V_{G_n}}^2}{100P_{G_n}}X'_{G_n}+\frac{P_{c_{kn}}sen\theta_{c_k}}{\sqrt{3}V_{G_T}}\frac{{V_{G_n}}^2}{100P_{G_n}}X'_{G_n}+\frac{V_{G_T}P_{c_{vn}}sen\theta_{c_v}}{\sqrt{3}{V_{c_{vn}}}^2}\frac{{V_{G_n}}^2}{100P_{G_n}}X'_{G_n}\Bigg]^2$$

$$+\Bigg[\frac{P_{C_{Kn}}cos\theta_{C_K}}{\sqrt{3}V_{G_T}}\frac{{V_{G_n}}^2}{100P_{G_n}}X'_{G_n}+\frac{V_{G_T}P_{C_{Vn}}cos\theta_{C_V}}{\sqrt{3}{V_{C_{Vn}}}^2}\frac{{V_{G_n}}^2}{100P_{G_n}}X'_{G_n}+\frac{V_{G_T}I_{M_{Pn}}cos\theta_{M_P}}{V_{M_{Pn}}}\frac{{V_{G_n}}^2}{100P_{G_n}}X'_{G_n}+$$

$$+\frac{P_{c_{kn}}cos\theta_{c_k}}{\sqrt{3}V_{G_T}}\frac{{V_{G_n}}^2}{100P_{G_n}}X'_{G_n}+\frac{V_{G_T}P_{c_{vn}}cos\theta_{c_v}}{\sqrt{3}{V_{c_{vn}}}^2}\frac{{V_{G_n}}^2}{100P_{G_n}}X'_{G_n}\Bigg]^2$$

$$\left[\frac{V_{G_A}}{\sqrt{3}}+\left(\frac{P_{c_{kn}}\,sen\,\theta_{c_k}}{V_{G_A}}+\frac{V_{G_A}P_{c_{vn}}sen\theta_{c_v}}{{V_{c_{vn}}}^2}\right)\frac{{V_{G_n}}^2}{100\sqrt{3}\,P_{G_n}}X'_{G_n}\right]^2+\Bigg[\Bigg(\frac{P_{c_{kn}}\cos\theta_{c_k}}{V_{G_A}}+$$

$$+\frac{V_{G_A}P_{c_{vn}}cos\theta_{c_v}}{{V_{c_{vn}}}^2}\Bigg)\frac{{V_{G_n}}^2}{100\sqrt{3}\,P_{G_n}}X'_{G_n}\Bigg]^2=\Bigg[\frac{V_{G_T}}{\sqrt{3}}+\Bigg(\frac{P_{C_{Kn}}sen\theta_{C_K}}{\sqrt{3}V_{G_T}}+\frac{V_{G_T}P_{C_{Vn}}sen\theta_{C_V}}{\sqrt{3}{V_{C_{Vn}}}^2}+$$

$$+\frac{V_{G_T}I_{M_{Pn}}sen\theta_{M_P}}{V_{M_{Pn}}}+\frac{P_{c_{kn}}sen\theta_{c_k}}{\sqrt{3}V_{G_T}}+\frac{V_{G_T}P_{c_{vn}}sen\theta_{c_v}}{\sqrt{3}{V_{c_{vn}}}^2}\Bigg)\frac{{V_{G_n}}^2}{100P_{G_n}}X'_{G_n}\Bigg]^2+$$

$$+\Bigg[\Bigg(\frac{P_{C_{Kn}}cos\theta_{C_K}}{\sqrt{3}V_{G_T}}+\frac{V_{G_T}P_{C_{Vn}}cos\theta_{C_V}}{\sqrt{3}{V_{C_{Vn}}}^2}+\frac{V_{G_T}I_{M_{Pn}}cos\theta_{M_P}}{V_{M_{Pn}}}+\frac{P_{c_{kn}}cos\theta_{c_k}}{\sqrt{3}V_{G_T}}+$$

$$+\frac{V_{G_T}P_{c_{vn}}cos\theta_{c_v}}{\sqrt{3}{V_{c_{vn}}}^2}\Bigg)\frac{{V_{G_n}}^2}{100P_{G_n}}X'_{G_n}\Bigg]^2$$

If we consider that:

$$x=X'_{G_n}$$

$$a_1=\frac{V_{G_A}}{\sqrt{3}}$$

$$b_1=\left(\frac{P_{c_{kn}}\,sen\,\theta_{c_k}}{V_{G_A}}+\frac{V_{G_A}P_{c_{vn}}sen\theta_{c_v}}{{V_{c_{vn}}}^2}\right)\frac{{V_{G_n}}^2}{100\sqrt{3}\,P_{G_n}}$$

$$c_1=\left(\frac{P_{c_{kn}}\cos\theta_{c_k}}{V_{G_A}}+\frac{V_{G_A}P_{c_{vn}}cos\theta_{c_v}}{{V_{c_{vn}}}^2}\right)\frac{{V_{G_n}}^2}{100\sqrt{3}\,P_{G_n}}$$

$$a_2=\frac{V_{G_T}}{\sqrt{3}}$$

$$b_2=\Bigg(\frac{P_{C_{Kn}}sen\theta_{C_K}}{\sqrt{3}V_{G_T}}+\frac{V_{G_T}P_{C_{Vn}}sen\theta_{C_V}}{\sqrt{3}{V_{C_{Vn}}}^2}+\frac{V_{G_T}I_{M_{Pn}}sen\theta_{M_P}}{V_{M_{Pn}}}+\frac{P_{c_{kn}}sen\theta_{c_k}}{\sqrt{3}V_{G_T}}+$$

$$+\frac{V_{G_T}P_{c_{vn}}sen\theta_{c_v}}{\sqrt{3}{V_{c_{vn}}}^2}\Bigg)\frac{{V_{G_n}}^2}{100P_{G_n}}$$

$$c_2=\Bigg(\frac{P_{C_{Kn}}cos\theta_{C_K}}{\sqrt{3}V_{G_T}}+\frac{V_{G_T}P_{C_{Vn}}cos\theta_{C_V}}{\sqrt{3}{V_{C_{Vn}}}^2}+\frac{V_{G_T}I_{M_{Pn}}cos\theta_{M_P}}{V_{M_{Pn}}}+\frac{P_{c_{kn}}cos\theta_{c_k}}{\sqrt{3}V_{G_T}}+$$

$$+\frac{V_{G_T}P_{c_{vn}}cos\theta_{c_v}}{\sqrt{3}{V_{c_{vn}}}^2}\Bigg)\frac{{V_{G_n}}^2}{100P_{G_n}}$$

We can write the featured equation as:

$$(a_1 + b_1x)^2 + (c_1x)^2 = (a_2 + b_2x)^2 + (c_2x)^2$$

$$a_1^2 + 2a_1b_1x + b_1^2x^2 + c_1^2x^2 = a_2^2 + 2a_2b_2x + b_2^2x^2 + c_2^2x^2$$

$$b_2^2x^2 - b_1^2x^2 + c_2^2x^2 - c_1^2x^2 + 2a_2b_2x - 2a_1b_1x + a_2^2 - a_1^2 = 0$$

$$\left(b_2^2 - b_1^2 + c_2^2 - c_1^2\right)x^2 + (2a_2b_2 - 2a_1b_1)x + \left(a_2^2 - a_1^2\right) = 0$$

The solution of the above equation will be the real and positive root of the equation below.

$$ax^2 + cx + e = 0$$

Where:

$$a = b_2^2 - b_1^2 + c_2^2 - c_1^2$$

$$c = 2a_2b_2 - 2a_1b_1$$

$$e = a_2^2 - a_1^2$$

$$x = \frac{-c + \sqrt{c^2 - 4ae}}{2a}$$

$$\boldsymbol{X'_{G_n}} = \frac{\boldsymbol{-c + \sqrt{c^2 - 4ae}}}{\boldsymbol{2a}}$$

Where $X'_{G_n}$ is the maximum value calculated for transient reactance of the alternator, which meets user-defined requirements.

## 11 PREPARATION OF EXCEL SPREADSHEETS

Excel spreadsheets were elaborated based on the concepts developed in this technical information. The theoretical part is not indispensable for its use, but it is important for understanding the problem and possible development of further studies.

Two spreadsheets were elaborated to determine the transient reactance of the alternator, and two to calculate the voltage in the alternator terminals. For each calculation there is a complete and a simplified one, both in a single file. In the complete spreadsheets are indicated the formulas and terms used in the calculation and, in the simplified ones, which are identical to the complete ones, only the basic information is visible.

Because the two spreadsheets are identical, the fields and information in the complete spreadsheets that are not visible in the simplified worksheets are hidden but still active. Therefore, any change, or introduction of information, should be done with care not to corrupt the file.

Spreadsheets can be used for 50 or 60Hz systems, with appropriate adjustments, and for any voltage values of the systems and loads.

Because in an installation there may be loads with nominal voltages different from that of the system, there are fields to fill in this information. For example, there may be motors and loads with nominal voltages of 220V, 380V, 440V, 460V, 480, etc.

Fields with loads power factors were also left to be filled with the actual data.

The spreadsheets are for all cases, that is, the alternator may or may not be with initial load, this initial load can be formed by constant or variable load. The load to be applied, being the alternator with initial load, can be one or more types of loads, constants, variables, or motor(s).

The reference made to motor(s) is to allow the consider of a single motor or set of motors, whose data must be defined by the user. For example, if one wishes to determine the values of the transient reactance and the voltage in the alternator terminals, with the simultaneous start of two motors with different characteristics, the equivalent values of the starting currents and the power factor corresponding to the two engines must be reported in the spreadsheets.

To avoid errors and inconsistencies in the results, the completion of the fields of the spreadsheets must be done correctly and, the informed data, should be consistent with the limitations of equipment and loads.

### 11.1 Transient Reactance Calculation Spreadsheets

The alternator transient reactance calculation spreadsheets are designed to define the maximum transient reactance value, which ensures that the voltage at the alternator terminals will be equal to or greater than the user-defined value, considering that the group is operating with or without initial loads and, during normal operation, are applied, individually or together, constant or variable power loads, or motor starting.

As the values of the transient reactance usually do not correspond to the nominal powers of the alternators found on the market, the user must choose the combination of rated power and transient reactance, which meets their needs.

### 11.2 Terminals' Voltages Calculation Spreadsheets

The calculation spreadsheets of the voltage in the alternator terminals were elaborated to, based on the alternator data, and loads data, determine the voltage in their terminals to develop the studies of the behavior of the systems and calculate the other components of the installation.

Special attention should be done to the value of the adjusted operating voltage, as this value may be higher than the rated voltage of the alternator and system. In the case of emergency groups, this value may be close to the maximum value bearable by the components of the installation. The limits of voltage and load power adjustments must be respected so that they do not exceed the limits set by the equipment and loads.

The total continuous power applied to the alternator shall not exceed the permissible power set by the generator set manufacturer. The total continuous power applied may even be greater than the rated power of the alternator, but its value and duration time must be set and administered by the user.

**Important**: Theoretically, when the group is operating with permanent load, the voltage in the alternator terminals will be kept constant by the automatic voltage regulator, at the user-adjusted value, for any load values that are within the group capacities.

To calculating the voltage at the alternator terminals, the maximum voltage value $V_G$ of the alternator was limited in function of the maximum value of the operating adjustment voltage $V_{G_A}$, with the alternator operating with rated power and rated power factor. Typically, the value of the maximum adjusted voltage $V_{G_A}$ is 110% of the rated voltage. Therefore, for these cases, the maximum voltage $V_G$ of the alternator should consider that the power supplied by the group is the rated power of the alternator, with a power factor equal to 0. 8.

## 12 EXEMPLO COMENTADO DE APLICAÇÃO

Spreadsheets allow the user to quickly simulate many alternatives. However, in this technical information will be made only some of these simulations.

### 12.1 Example

Whereas in an installation one wishes to calculate the transient reactance and voltages in the terminals of an alternator, the required rated power of which was defined at 1000kVA and that:

1 - The rated voltage of the system: 480V

2 - Rated alternator voltage: 480V.

3 - Minimum voltage allowed in alternator terminals: 95% of the rated voltage, i.e., 456V.

4 – The operating voltage of the alternator will be adjusted at 105% of the rated voltage, i.e., 504V.

5 - The initial load of the group, composed of constant power loads, totals 350kVA, with rated voltage of 460V and power factor 0.85.

6 - The initial load of the group, composed of variable power loads, totals 250kVA, with rated voltage of 480V and power factor 0.9.

7 - When the group operates at the initial load, the power supply of a frame with the following loads will be connected, which will be applied together:

- Constant power load of 50kVA, 460V and power factor 0.85.
- Variable power load of 100kVA, 480V and power factor 0.9.
- A 75hp, 460V induction motor, 710A starting current with 0.30 power factor.
- A 30hp, 460V induction motor, 320A starting current with 0.35 power factor.

### 12.2 Alternator Choice

Because the rated power of the alternator was defined based on a study, which is not scope of this technical information, the first step is to determine the transient reactance of the alternator based on the data provided.

To be able to fill out the spreadsheet of the calculation of the transient reactance it is necessary to calculate the equivalent starting current and equivalent power factor of the 75hp and 30hp motors, which is shown in the table below:

| Motor | Rated Voltage | Starting Current | Power Factor |
|---|---|---|---|
| 75hp | 460 | 710 | 0,3 |
| 30hp | 460 | 320 | 0,35 |
| Equivalente | 460 | 1030 | 0,32 |

Filling the spreadsheet with the data we have:

| DATA SYSTEM | | | | |
|---|---|---|---|---|
| Alternator | | $VG_n$ | Rated Voltage of Alternator (V) | 480 |
| Alternator | | $VG_A$ | Adjusted Voltage of Operating the Alternator (V) | 504 |
| Alternator | | $PG_n$ | Rated Power of Alternator (kVA) | 1000 |
| Alternator | | $VG_T$ | Voltage at Alternator Terminals (V) | 456 |
| Loads Data | Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 350 |
| 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) | 250 |
| Loads Data | Initial | $Vc_{vn}$ | Rated Voltage of Initial Variable Load (V) | 460 |
| 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) | 50 |
| Loads Data | Load to be Applied | $VC_{Kn}$ | Rated Voltage of Constant Load (V) | 460 |
| Loads Data | Load to be Applied | $FPC_K$ | Power Factor of Constant Load | 0,85 |
| Loads Data | Load to be Applied | $PC_{Vn}$ | Rated Power of Variable Load (kVA) | 100 |
| Loads Data | Load to be Applied | $VC_{Vn}$ | Rated Voltage of Variable Load (V) | 480 |
| Loads Data | Load to be Applied | $FPC_V$ | Power Factor of Variable Load | 0,9 |
| 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) | 1030 |
| Loads Data | Load to be Applied | $FPM_P$ | Power Factor of Motor(s) at Starting | 0,32 |

| | | |
|---|---|---|
| *Transient Reactance of Alternator* | $X'G_n$ (%) | **10,98** |

That is, the 1000kVA alternator that meets the above need should have a maximum nominal transient reactance of 10.98%. From the data of the WEG alternators, line AG10, we have the data below:

Linha AG10 - AG10

| Modelo | 480 V - Y / 240 V - YY | | | | | |
|---|---|---|---|---|---|---|
| | ΔT | 80 °C | 105 °C | 125 °C | 150 °C | 163 °C |
| 280MI30AI | kVA | 456 | 510 | **570** | 600 | 650 |
| | kW | 365 | 408 | **456** | 480 | 520 |
| 280MI40AI | kVA | 484 | 565 | **605** | 650 | 691 |
| | kW | 387 | 452 | **484** | 520 | 553 |
| 315MI10AI | kVA | 520 | 596 | **650** | 700 | 750 |
| | kW | 416 | 477 | **520** | 560 | 600 |
| 315MI15AI | kVA | 570 | 650 | **710** | 780 | 825 |
| | kW | 456 | 520 | **568** | 624 | 660 |
| 315MI20AI | kVA | 642 | 736 | **803** | 875 | 906 |
| | kW | 514 | 589 | **642** | 700 | 725 |
| 315MI30AI | kVA | 740 | 850 | **925** | 1010 | 1056 |
| | kW | 592 | 680 | **740** | 808 | 845 |
| 315MI40AI | kVA | 832 | 953 | **1040** | 1100 | 1160 |
| | kW | 666 | 763 | **832** | 880 | 928 |
| 355MI70AI | kVA | 1120 | 1283 | **1400** | 1450 | 1520 |
| | kW | 896 | 1026 | **1120** | 1160 | 1216 |
| 355MI80AI | kVA | 1280 | 1466 | **1600** | 1660 | 1720 |
| | kW | 1024 | 1173 | **1280** | 1328 | 1376 |
| 355MI90AI | kVA | 1440 | 1650 | **1800** | 1950 | 2000 |
| | kW | 1152 | 1320 | **1440** | 1560 | 1600 |

Linha AG10 - AG10

| Modelo | Xd' (%) Saturada 220/440 V |
|---|---|
| 250SI10AI | 17,43 |
| 250SI20AI | 18,39 |
| 250MI00AI | 18,40 |
| 250MI10AI | 16,58 |
| 250MI20AI | 16,40 |
| 280MI20AI | 16,53 |
| 280MI30AI | 19,70 |
| 280MI40AI | 13,80 |
| 315MI10AI | 20,40 |
| 315MI15AI | 19,25 |
| 315MI20AI | 19,50 |
| 315MI30AI | 17,18 |
| 315MI40AI | 17,70 |
| 355MI70AI | 16,50 |
| 355MI80AI | 20,00 |
| 355MI90AI | 24,20 |

Based on the rated power, we can choose the 1040kVA Model 315MI40AI alternator. The nominal transient reactance, at 440V, is 17.18%, which referred to the voltage of 480V and power and 1000kVA is:

$$Z_{G(480)} = Z_{G(440)} \frac{440^2.1000}{480^2.1040}$$

$$Z_{G(480)} = 17{,}7 \frac{440^2.1000}{480^2.1040} = 14{,}30\%$$

This alternator does not meet the calculated value of 10.98%.

Moving to the 1400kVA Model 355MI70AI alternator, whose nominal transient reactance at 440V is 16.5%, which referred to the voltage of 480V and power and 1000kVA is:

$$Z_{G(480)} = 16{,}5 \frac{440^2.1000}{480^2.1400} = 9{,}90\%$$

The alternator meets the required requirements.

## 12.3 Voltages in Alternator Terminals

The rated voltage of the Alternator Model 355MI70AI will be 480 and the rated reactance referred to the 480V voltage and 1400kVA power will be:

$$Z_{G(480)} = 16{,}5 \frac{440^2}{480^2} = 13{,}865\%$$

The voltage in the terminals of the 1400kVA Model 355MI70AI alternator, under the conditions defined in the example will be 460.48V, i.e., higher than the minimum required value of 456V.

| DATA SYSTEM | | | | |
|---|---|---|---|---|
| Alternator | | $VG_n$ | Rated Voltage of Alternator (V) | 480 |
| | | $VG_A$ | Adjusted Voltage of Operating the Alternator (V) | 504 |
| | | $PG_n$ | Rated Power of Alternator (kVA) | 1400 |
| | | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 13,865 |
| Loads Data | Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 350 |
| | | $Vc_{kn}$ | 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) | 250 |
| | | $Vc_{vn}$ | 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) | 50 |
| | | $VC_{Kn}$ | Rated Voltage of Constant Load (V) | 460 |
| | | $FPC_K$ | Power Factor of Constant Load | 0,85 |
| | | $PC_{Vn}$ | Rated Power of Variable Load (kVA) | 100 |
| | | $VC_{Vn}$ | 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) | 1030 |
| | | $FPM_P$ | Power Factor of Motor(s) at Starting | 0,32 |

| | | |
|---|---|---|
| *Voltage at the Alternator Terminals (V)* | $V_{GT}$ (%) | **460,48** |

### 12.4 Comments

As can be seen, the use of spreadsheets allows to make many simulations and analyze alternatives that can be adopted, checking the behavior of voltages for various load situations.

As one will hardly find an alternator with the defined nominal power and nominal transient reactance calculated with the aid of the spreadsheet, the best solution is to, by consulting the data of the alternators on the market, choosing the one that most closely approximates the necessary characteristics, as was done in the example.

The choice of the 1400kVA rated power alternator does not imply that the diesel generator set should have this capacity. Therefore, the group can have a rated power of 1000kVA with alternator of 1400kVA.

Through simulations, one can explore other situations that can meet the needs of the installation, without being exactly those initially defined. For example, you can reduce the value of the minimum permissible voltage at the alternator terminals, increase the value of the adjusted operating voltage, or even by combining the two options.

An alternative that will be analyzed is the change in operating conditions. For example, delay the start of the engine of 75hp for a few seconds, that is, in a first phase applies the load considered, except the 75hp engine, which would apply in the second phase.

Considering the 1040kVA Model 315MI40AI alternator, the transient reactance of 17.7% at 440V referred to the 480V voltage will be:

$$Z_{G(480)} = 17{,}7\frac{440^2}{480^2} = 14{,}873\%$$

| DATA SYSTEM | | | | |
|---|---|---|---|---|
| Alternator | | $VG_n$ | Rated Voltage of Alternator (V) | 480 |
| Alternator | | $VG_A$ | Adjusted Voltage of Operating the Alternator (V) | 504 |
| Alternator | | $PG_n$ | Rated Power of Alternator (kVA) | 1040 |
| Alternator | | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 14,873 |
| Loads Data | Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 350 |
| 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) | 250 |
| 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) | 50 |
| Loads Data | Load to be Applied | $VC_{Kn}$ | Rated Voltage of Constant Load (V) | 460 |
| Loads Data | Load to be Applied | $FPC_K$ | Power Factor of Constant Load | 0,85 |
| Loads Data | Load to be Applied | $PC_{Vn}$ | Rated Power of Variable Load (kVA) | 100 |
| Loads Data | Load to be Applied | $VC_{Vn}$ | Rated Voltage of Variable Load (V) | 480 |
| Loads Data | Load to be Applied | $FPC_V$ | Power Factor of Variable Load | 0,9 |
| 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) | 320 |
| Loads Data | Load to be Applied | $FPM_P$ | Power Factor of Motor(s) at Starting | 0,35 |

| | | |
|---|---|---|
| *Voltage at the Alternator Terminals (V)* | $V_{GT}$ (%) | **479,79** |

Therefore, the voltage in the alternator terminals would be 479.79V in the first phase.

| DATA SYSTEM | | | | |
|---|---|---|---|---|
| Alternator | | $VG_n$ | Rated Voltage of Alternator (V) | 480 |
| | | $VG_A$ | Adjusted Voltage of Operating the Alternator (V) | 504 |
| | | $PG_n$ | Rated Power of Alternator (kVA) | 1040 |
| | | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 14,873 |
| Loads Data | Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 430 |
| | | $Vc_{kn}$ | 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) | 350 |
| | | $Vc_{vn}$ | 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) | 710 |
| | | $FPM_P$ | Power Factor of Motor(s) at Starting | 0,3 |

| | | |
|---|---|---|
| *Voltage at the Alternator Terminals (V)* | $V_{GT}$ *(%)* | **463,40** |

In the second phase, where only 75hp motor starts, with a difference of a few seconds after the first (voltage stabilization time at alternator terminals). During the start of the 75hp motor, the voltage in the alternator terminals will be 463.40V. At this stage, considering that the motor is a constant power load and that 1hp=1kVA, the motor load of 30hp is included in the initial constant power load.

## 12.5 Additional Comments

In these comments will be addressed the problems of overloads with limitation of the alternator voltage $V_G$, which change the adjusted operating voltage $V_{G_A}$, and compatibility of the values of the loads.

### 12.5.1 Voltage Limitation $V_G$ of the Alternator

As, theoretically, the voltage regulator should keep the voltage constant in the alternator terminals, for any applied load value and provided that the diesel engine has the capacity for this, the voltage value $V_G$ would be unlimited. However, as this does not occur, in the spreadsheets of this technical information it was established that the maximum voltage value $V_G$ will be the voltage calculated when the alternator feeds a constant load of power equal to the rated power of the alternator, with power factor 0.8 (normal standard of group manufacturers), and the load rated voltage equal to the nominal voltages of the alternator and system, and for voltage adjusted operating $V_{G_A}$.

For the alternator Model 355MI70AI, 1400kVA, 480V, nominal transient reactance 13.865%, operating voltage $V_{G_A}$ adjusted at 504V, the voltage in the alternator terminals will be 504V, as adjusted, and the maximum voltage $V_G$ of the alternator, for the adjusted value $V_{G_A}$ will be 544.40V, which can be seen in the information of complete spreadsheet.

| DATA SYSTEM | | | | |
|---|---|---|---|---|
| Alternator | | $VG_n$ | Rated Voltage of Alternator (V) | 480 |
| | | $VG_A$ | Adjusted Voltage of Operating the Alternator (V) | 504 |
| | | $PG_n$ | Rated Power of Alternator (kVA) | 1400 |
| | | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 13,865 |
| Loads Data | Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 1400 |
| | | $Vc_{kn}$ | Rated Voltage of Initial Constant Load (V) | 480 |
| | | $FPc_k$ | Power Factor of Initial Constant Load | 0,8 |
| | | Voltage at the Alternator Terminals (V) | $V_{GT}$ (%) | 504,00 |

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{P_{c_{kn}}\, sen\,\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} sen\theta_{c_v}}{V_{c_{vn}}{}^2}\right)\frac{V_{G_n}{}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \left[\left(\frac{P_{c_{kn}}\cos\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}}\cos\theta_{c_v}}{V_{c_{vn}}{}^2}\right)\frac{V_{G_n}{}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}$$

| $V_G(V)$ | 544,40 |
|---|---|

$$V_{G_{MAX}} = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{0,6V_{G_n}{}^2 X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right]^2 + \left(\frac{0,8V_{G_n}{}^2 X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right)^2\right)^{\frac{1}{2}}$$

| $V_G(V)$ | 544,40 |
|---|---|

| $V_G(V)$ | 544,40 |
|---|---|

$V_G$ – Alternator Voltage (V)

If the adjusted voltage value is, for example 528V (480V + 10%), the voltage in the alternator terminals will be 528V and the maximum alternator voltage $V_G$ will be 566.37V.

| DATA SYSTEM | | | | |
|---|---|---|---|---|
| Alternator | | $VG_n$ | Rated Voltage of Alternator (V) | 480 |
| | | $VG_A$ | Adjusted Voltage of Operating the Alternator (V) | 528 |
| | | $PG_n$ | Rated Power of Alternator (kVA) | 1400 |
| | | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 13,865 |
| Loads Data | Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 1400 |
| | | $Vc_{kn}$ | Rated Voltage of Initial Constant Load (V) | 480 |
| | | $FPc_k$ | Power Factor of Initial Constant Load | 0,8 |
| | | Voltage at the Alternator Terminals (V) | $V_{GT}$ (%) | 528,00 |

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{P_{c_{kn}}\, sen\,\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} sen\theta_{c_v}}{V_{c_{vn}}{}^2}\right)\frac{V_{G_n}{}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \left[\left(\frac{P_{c_{kn}}\cos\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}}\cos\theta_{c_v}}{V_{c_{vn}}{}^2}\right)\frac{V_{G_n}{}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}$$

| $V_G(V)$ | 566,37 |
|---|---|

$$V_{G_{MAX}} = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{0,6V_{G_n}{}^2 X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right]^2 + \left(\frac{0,8V_{G_n}{}^2 X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right)^2\right)^{\frac{1}{2}}$$

| $V_G(V)$ | 566,37 |
|---|---|

| $V_G(V)$ | 566,37 |
|---|---|

$V_G$ – Alternator Voltage (V)

With the limitation of the maximum voltage $V_G$, if the load is higher than the rated power of the alternator, the voltage value at the alternator terminals will be less than the adjusted operating value $V_{G_A}$, due to the imposed limit.

Whereas the alternator load, instead of 1400kVA is 1800kVA, for the operating voltage value $V_{G_A}$ set at 504V, the voltage in the terminals will be 489.95V instead of 504V.

| DATA SYSTEM | | | |
|---|---|---|---|
| Alternator | $VG_n$ | Rated Voltage of Alternator (V) | 480 |
| | $VG_A$ | Adjusted Voltage of Operating the Alternator (V) | 504 |
| | $PG_n$ | Rated Power of Alternator (kVA) | 1400 |
| | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 13,865 |
| Loads Data – Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 1800 |
| | $Vc_{kn}$ | Rated Voltage of Initial Constant Load (V) | 480 |
| | $FPc_k$ | Power Factor of Initial Constant Load | 0,8 |
| Voltage at the Alternator Terminals (V) | | $V_{GT}$ (%) | 489,95 |

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{P_{c_{kn}} sen\,\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} sen\theta_{c_v}}{V_{c_{vn}}^{\ 2}}\right)\frac{V_{G_n}^{\ 2} X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \left[\left(\frac{P_{c_{kn}} \cos\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} cos\theta_{c_v}}{V_{c_{vn}}^{\ 2}}\right)\frac{V_{G_n}^{\ 2} X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}$$

| $V_G(V)$ | 556,73 |
|---|---|

$$V_{G_{MAX}} = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{0,6V_{G_n}^{\ 2} X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right]^2 + \left(\frac{0,8V_{G_n}^{\ 2} X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right)^2\right)^{\frac{1}{2}}$$

| $V_G(V)$ | 544,40 |
|---|---|

| $V_G(V)$ | 544,40 |
|---|---|

$V_G$ – Alternator Voltage (V)

Note in the complete spreadsheet that the alternator voltage $V_G$ was limited to 544.40V for the voltage $V_{G_A}$ adjusted at 504V, but to keep the voltage at the adjusted value, the alternator voltage $V_G$ should be 556.73V.

| DATA SYSTEM | | | |
|---|---|---|---|
| Alternator | $VG_n$ | Rated Voltage of Alternator (V) | 480 |
| | $VG_A$ | Adjusted Voltage of Operating the Alternator (V) | 528 |
| | $PG_n$ | Rated Power of Alternator (kVA) | 1400 |
| | $Z'G_n$ | Rated Transient Reactance of Alternator (%) | 13,865 |
| Loads Data – Initial | $Pc_{kn}$ | Rated Power of Initial Constant Load (kVA) | 1800 |
| | $Vc_{kn}$ | Rated Voltage of Initial Constant Load (V) | 480 |
| | $FPc_k$ | Power Factor of Initial Constant Load | 0,8 |
| Voltage at the Alternator Terminals (V) | | $V_{GT}$ (%) | 514,91 |

For the operating voltage value $V_{G_A}$ set at 528V, the voltage in the terminals will be 514.91V instead of 528V.

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{P_{c_{kn}}\, sen\,\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} sen\theta_{c_v}}{V_{c_{vn}}^2}\right)\frac{V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \left[\left(\frac{P_{c_{kn}} \cos\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A}P_{c_{vn}}\cos\theta_{c_v}}{V_{c_{vn}}^2}\right)\frac{V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}$$

| | |
|---|---|
| $V_G(V)$ | 578,03 |

$$V_{G_{MAX}} = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{0,6V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right]^2 + \left(\frac{0,8V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right)^2\right)^{\frac{1}{2}}$$

| | |
|---|---|
| $V_G(V)$ | 566,37 |

| | |
|---|---|
| $V_G(V)$ | 566,37 |

$V_G-$ *Alternator Voltage (V)*

Likewise, the alternator voltage $V_G$ was limited to 566.37V for the voltage $V_{G_A}$ set at 528V, but to keep the voltage at the adjusted value, the alternator voltage $V_G$ should be 578.03V.

If you wish to stop limiting the maximum voltage value $V_G$ of the alternator, another limit should be imposed. For example, considering the example cited, where the alternator load, instead of 1400kVA is 1800kVA, for the operating voltage value $V_{G_A}$ set at 528V the voltage in the terminals will be 514.91V instead of 528V because the voltage $V_G$ was limited to 566.37V.

If we impose the value of 578.03V to $V_G$, we will see that the voltage in the terminals will be maintained at the value of the adjusted operating voltage $V_{G_A}$. The value to be imposed must be entered in the complete spreadsheet, in the field indicated in the figure below:

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{P_{c_{kn}}\, sen\,\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} sen\theta_{c_v}}{V_{c_{vn}}^2}\right)\frac{V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \left[\left(\frac{P_{c_{kn}} \cos\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A}P_{c_{vn}}\cos\theta_{c_v}}{V_{c_{vn}}^2}\right)\frac{V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}$$

| | |
|---|---|
| $V_G(V)$ | #DIV/0! |

$$V_{G_{MAX}} = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{0,6V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right]^2 + \left(\frac{0,8V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right)^2\right)^{\frac{1}{2}}$$

| | |
|---|---|
| $V_G(V)$ | 578,03 |

| | |
|---|---|
| $V_G(V)$ | #DIV/0! |

$V_G-$ *Alternator Voltage (V)*

Thus, for loads of, for example, 800kVA, 1400kVA and 1800kVA, the voltage in the alternator terminals will be kept at the adjusted value, with the following information from the complete worksheet:

For 800kVA:

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{P_{c_{kn}}\, sen\,\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} sen\theta_{c_v}}{V_{c_{vn}}^2}\right)\frac{V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \left[\left(\frac{P_{c_{kn}} \cos\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A}P_{c_{vn}}\cos\theta_{c_v}}{V_{c_{vn}}^2}\right)\frac{V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}$$

| | |
|---|---|
| $V_G(V)$ | 549,44 |

$$V_{G_{MAX}} = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{0,6V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right]^2 + \left(\frac{0,8V_{G_n}^2 X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right)^2\right)^{\frac{1}{2}}$$

| | |
|---|---|
| $V_G(V)$ | 578,03 |

| | |
|---|---|
| $V_G(V)$ | 549,44 |

$V_G-$ *Alternator Voltage (V)*

For 1400kVA:

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{P_{c_{kn}}\,sen\,\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} sen\theta_{c_v}}{V_{c_{vn}}^{2}}\right)\frac{V_{G_n}^{2} X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \left[\left(\frac{P_{c_{kn}}\cos\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} \cos\theta_{c_v}}{V_{c_{vn}}^{2}}\right)\frac{V_{G_n}^{2} X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}$$

$V_G(V)$ 566,37

$$V_{G_{MAX}} = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{0,6 V_{G_n}^{2} X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right]^2 + \left(\frac{0,8 V_{G_n}^{2} X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right)^2\right)^{\frac{1}{2}}$$

$V_G(V)$ 578,03

$V_G(V)$ 566,37

$V_G -$ *Alternator Voltage (V)*

For 1800kVA:

$$V_G = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \left(\frac{P_{c_{kn}}\,sen\,\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} sen\theta_{c_v}}{V_{c_{vn}}^{2}}\right)\frac{V_{G_n}^{2} X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2 + \left[\left(\frac{P_{c_{kn}}\cos\theta_{c_k}}{V_{G_A}} + \frac{V_{G_A} P_{c_{vn}} \cos\theta_{c_v}}{V_{c_{vn}}^{2}}\right)\frac{V_{G_n}^{2} X'_{G_n}}{100\sqrt{3}\,P_{G_n}}\right]^2\right)^{\frac{1}{2}}$$

$V_G(V)$ 578,03

$$V_{G_{MAX}} = \sqrt{3}\left(\left[\frac{V_{G_A}}{\sqrt{3}} + \frac{0,6 V_{G_n}^{2} X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right]^2 + \left(\frac{0,8 V_{G_n}^{2} X'_{G_n}}{100\sqrt{3}\,V_{G_A}}\right)^2\right)^{\frac{1}{2}}$$

$V_G(V)$ 578,03

$V_G(V)$ 578,03

$V_G -$ *Alternator Voltage (V)*

12.5.2 Information and Values Compatibility

The information of the values to be filled in the worksheets must be observed for the calculations to be more accurate. This information is:

a) For alternators:

Rated powers, rated voltages, adjusted operating voltages, adjustment ranges of operating voltages, overload values and their duration, transient reactance, and reference values. The application of this information was explored in the example considered in this technical information.

b) For Loads of Constant Power:

Rated powers, rated voltages, power factor. In the application of these loads, with the alternator with or without initial load, these values should be informed because they are used in the calculations. However, when considering as initial load, there is a difference between the value of the individual loads and the equivalent value. For example, considering an alternator:

- No load and the application of a constant load of, for example, 100kVA, rated voltage 460V, power factor 0.9.

- With the constant initial load of 100kVA power factor 0.9 and the application of a constant load of 200kVA, rated voltage 480V, power factor 0.8.

After the application of the second constant load, with the alternator being with the initial load, the final load will be an equivalent constant load of:

| Loads of Constant Power | | | | |
|---|---|---|---|---|
| Load (KVA) | Rated Voltage | Power Factor | kW | kVAR |
| 100 | 480 | 0,9 | 90 | 44 |
| 200 | 440 | 0,8 | 160 | 120 |
| 300 | (1) | 0,84 | 250 | 164 |

(1) For all purposes, as the load is constant power, the nominal load voltage value is not relevant. Therefore, it can be 480V or 460V.

The total load will be the sum of the two nominal powers.

c) For Loads of Variable Power:

Rated powers, rated voltages, power factor. In the application of these loads, with the alternator with or without initial load, these values should be informed because they are used in the calculations. However, when considering as initial load, there is also a difference between the value of the individual loads and the equivalent value. For example, considering an alternator:

- No load and the application of a variable load of, for example, 100kVA, rated voltage 480V, power factor 0.9.

- With the variable initial load of 100kVA power factor 0.9 and the application of a variable load of 200kVA, rated voltage 440V, power factor 0.8.

After the application of the second variable load, with the alternator with the initial load, the final load will be a variable load of:

| Loads of Variable Power | | | | |
|---|---|---|---|---|
| Load (KVA) | Rated Voltage | Power Factor | kW | kVAR |
| 100 | 480 | 0,9 | 90 | 44 |
| 200 | 440 | 0,8 | 190 | 143 |
| 337 | (1) | 0,83 | 280 | 186 |

(1) As the load is of variable power, the value of the rated voltage of the loads must be the same, because the power varies with the square of the voltage variation. Preferably adopt the rated voltage value of the initial load in case 480V.

d) For Motors:

The application of this information was explored in the example considered in this technical information.

e) Observations

The application of care with the compatibility of units and values of loads is a practice to obtain greater precision in the result. Therefore, this care does not need to be so rigorous for approximate calculations.

Corrections of values are not necessary for the application of loads, constant power and/or variable, when the alternator is at initial load.