Method of Homopolar Balance of Phases Caused by Charges (Case of Kinshasa Distribution Power grid).

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Abstract:

In this article, we present the models of electronic regulation of the speed of the industrial ring engine by modeling the voltage inverter. These models are based by pulse width modulation; switching moments are determined by the intercession points between the carrier and the modulant. The switch switches switch frequency is fixed by the carrier. The engine is modeled from the voltages we note $\boldsymbol{V_{an}}, \boldsymbol{V_{bn}}$ and the inverter is controlled by logical sizes.

The MLI control is very usable for the control of the asynchronous engine, based on the comparison between two signals, which is made the generation of pulse sequences.

Keywords **— Method, homopolar imbalance, phases, charges, electrical network, distribution.**

I. INTRODUCTION

For many years, the electricity distributor has been working to ensure the quality of electricity supply. Initial efforts have focused on continuity of service in order to make access to energy available to the user. Today, quality criteria have evolved with the development of equipment where electronics take a prominent place in control and control systems. Electrical energy is provided in the form of voltage constituting a three-phase sinusoidal system whose characteristic parameters are the following, the frequency, the amplitude of the three voltages, the waveform that must be as close as possible to a sinusoid, the imbalance the symmetry of the three-phased system, characterized by the equality of the modules of the three voltages and their relative phase shift.

II. MLI CONTROL TECNICS

A. MLI to Hysteresis Band

The hysteresis band method allows the switches to be switched from the straightener when the error between the signal and its caller exceeds a fixed amplitude. This amplitude is commonly called a fork or hysteresis band, which only requires one hysteresis comparator per phase.

1) Modeling the MLI straightener:

The following figure presents the unified pattern of a straightener bridge connected to the network, e is source voltage and R, L are the parameters of the line, v is the tension of straightener. The line current i is controlled by the voltage drop produced by the L induction, and the R resistance of the line and the v straightener input voltage.

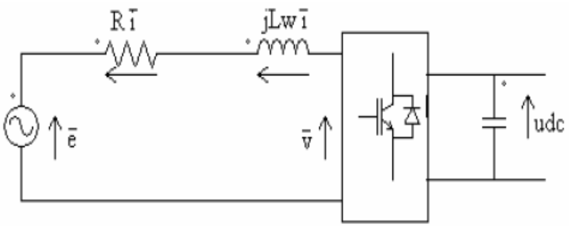

Fig. 1 Unified scheme of a straightener bridge connected to the network.

2) Switch States

From this table one can write the righting input tensions in general as follows:

$$v_{ab} = (S_a - S_b)U_{dc} \qquad (2.1)$$
$$v_{bc} = (S_b - S_c)U_{dc} \qquad (2.2)$$
$$v_{ca} = (S_c - S_a)U_{dc} \qquad (2.3)$$

From this we can deduce the simple voltages:

$$f_a = \frac{2S_a - (S_b + S_c)}{3} \qquad (2.4)$$
$$f_b = \frac{2S_b - (S_a + S_c)}{3} \qquad (2.5)$$
$$f_c = \frac{2S_c - (S_c + S_b)}{3} \qquad (2.6)$$

The author considered the relationship (2.4) to present the eight possible states of the input voltage v in a complex plan: αβ:

$$v_{k+1} \begin{cases} (2/3) \\ v_7 = v_0 = 0^{U_{dc}} \end{cases} e^{jk\pi/3} \; pour \; k \; (2.5)$$

3) Functional representation of the MLI straightener in the three-phase repository

Voltage equations for the three-phase balanced system without neutral can be written as :

$$\bar{e} = \bar{v_1} + \bar{v} \qquad (2.6)$$
$$\bar{e} = R_{\bar{\imath}+} L\frac{d_{\bar{\imath}}}{dt} + \bar{v} \qquad (2.7)$$
$$\begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} = R\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + L\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (2.8)$$

And the righter's input voltage can be written as follows:

$$v_n = U_{dc}\left(S_n - \frac{1}{3}\sum_{n=a}^{c} S_n\right) \qquad (2.9)$$

Where $S_n = 0$ or 1, are the state of the switches, where (n = a, b, c); in addition, the DC bus current can be written as

$$C = \frac{dU_{dc}}{dt} = i_c \qquad (2.10)$$

The current in the capacitor can also write

$$i_c = i_{dc} - i_{ch} \qquad (2.11)$$

$$C = \frac{dU_{dc}}{dt} = S_a i_a + S_b i_b + S_c i_c - i_{dc} \qquad (2.12)$$

Also, the current i_c is the sum of the product of the currents of each phase by the state of its switch

$$C = \frac{dU_{dc}}{dt} = S_a i_a + S_b i_b + S_c i_c - i_{ch} \qquad (2.13)$$

So, the alternate side of the rectifier

$$LL\frac{di_a}{dt} + Ri_a = e_a - U_{dc}\left(S_a - \frac{1}{3}\sum_{n=a}^{c} S_n\right) (2.14)$$
$$L\frac{di_a}{dt} + Ri_a = e_a - U_{dc}\left(S_a - \frac{1}{3}(S_a + S_b + S_c)\right) (2.15)$$
$$L\frac{di_b}{dt} + Ri_b = e_b - U_{dc}\left(S_b - \frac{1}{3}\sum_{n=a}^{c} S_n\right) (2.16)$$
$$L\frac{di_b}{dt} + Ri_b = e_b - U_{dc}\left(S_b - \frac{1}{3}(S_a + S_b + S_c)\right) (4.17)$$
$$L\frac{di_c}{dt} + Ri_c = e_c - U_{dc}\left(S_c - \frac{1}{3}\sum_{n=a}^{c} S_n\right) (4.18)$$
$$L\frac{di_c}{dt} + Ri_c = e_c - U_{dc}\left(S_c - \frac{1}{3}(S_a + S_b + S_c)\right) (4.19)$$

4) Network voltage equation

Where network tensions are expressed by:

$$e_a = E_m sin\omega t \qquad (2.20)$$
$$e_b = E_m sin\left(\omega t - \frac{2\pi}{3}\right) \qquad (2.21)$$
$$e_c = E_m sin\left(\omega t + \frac{2\pi}{3}\right) \qquad (2.22)$$

The preceding equation can be summarized as follo ws:

$$\left(L\frac{d}{dt} + R\right) i_n = e_n - U_{dc}\left(S_a - \frac{1}{3}\sum_{n=a}^{c} S_n\right) \quad (2.23)$$
$$C = \frac{dU_{dc}}{dt} = \sum_{n=a}^{c} i_n S_n - i_{ch} \qquad (2.24)$$

B. Functional representation of the MLI rectifier

5) Functional representation of the MLI rectifier in the fixed reference α

The equations of tension in the fixed coordinate s ystem α precede are obtained by applying the equati ons, (2.7) and (2.11) and are written as :

$$Ri_\alpha + L\frac{di_\alpha}{dt} = e_\alpha - U_{dc}S_\alpha \qquad (2.25)$$

$$Ri_\beta + L\frac{di_\beta}{dt} = e_\beta - U_{dc}S_\beta \qquad (2.26)$$

$$C = \sum_{k=\alpha}^{\beta} i_n S_n - \mathrm{i_{ch}} \qquad (2.27)$$

Where

$$S_\alpha = \frac{1}{\sqrt{6}}(2S_a - S_b - S_c) \qquad (2.28)$$

$$S_\beta = \frac{1}{\sqrt{2}}(S_b - S_c) \qquad (2.29)$$

6) ***Functional representation of the MLI rectifier in the rotating repository (dq)***

The equations in the dq rotating coordinate system are :

$$e_d = Ri_d + L\frac{di_d}{dt} - wLi_q + v_d \ (2.30)$$

$$e_q = Ri_q + L\frac{di_q}{dt} + wLi_d + v_q \quad (2.31)$$

$$C = \frac{dU_{dc}}{dt} = \frac{3}{2}\sum_{k=d}^{q} i_n S_n - \mathrm{i_{ch}} \ (2.32)$$

Where

$$\mathrm{S_d} = \mathrm{S_a} coswt + \mathrm{S_\beta} sinwt \qquad (2.33)$$

$$\mathrm{S_q} = \mathrm{S_\beta} coswt - \mathrm{S_\alpha} sinwt \qquad (2.34)$$

III. STATIC PHASE IMBALANCE COMPENSATION STUDY

C. Current Balance

To balance the instantaneous currents in the three phases at the secondary of the transformer, we propose to place in parallel on the three phases a static converter. The network can be modeled by the diagram in Figure 2

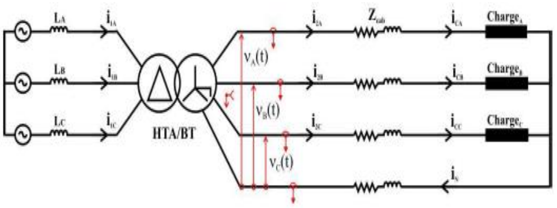

Fig. 2 Simplified equivalent diagram of an isolated neutral network

7) ***Model of a four-arm inverter in the three-phase unbalanced network***

When the charges in the three phases are known, we can determine the impedances of the charges as well as the passing currents in these charges:

$$Rc_{A,B,C} = U^2{}_{nom}.\frac{Pc_{A,B,C}}{\sqrt{Pc^2{}_{A,B,c} + Qc^2{}_{A,B,c}}} \qquad (3.1)$$

$$Xc_{A,B,C} = U^2{}_{nom}.\frac{Qc_{A,B,C}}{\sqrt{Pc^2{}_{A,B,c} + Qc^2{}_{A,B,c}}} \qquad (3.2)$$

Where and are the active and reactive load powers. From the above diagram, by applying the mesh law, we can solve the three currents passing through the loads:

$$\begin{cases} \underline{V_A} - \underline{V_B} + \left(\underline{I_A} - \underline{I_B}\right)\underline{Z_{cab}} + \underline{I_{CA}}.\underline{Z_{CA}} - \underline{I_{CB}}.\underline{Z_{CB}} = 0 \\ \underline{V_A} - \underline{V_C} + \left(\underline{I_A} - \underline{I_C}\right)\underline{Z_{cab}} + \underline{I_{CA}}.\underline{Z_{CA}} - \underline{I_{CC}}.\underline{Z_{CC}} = 0 \\ \underline{V_A} + \left(\underline{I_A} - \underline{I_N}\right)\underline{Z_{cab}} + \underline{I_{CA}}.\underline{Z_{CA}} = 0 \\ \underline{I_A} + \underline{I_B} + \underline{C} = \underline{I_N} \end{cases} \qquad (3.3)$$

Where $\underline{Z_{CA}}$, $\underline{Z_{CB}}$ and $\underline{Z_{CC}}$ are the impedances of three charges and Z_cab is the impedance of the cable in the electrical network

$$\underline{Z}_{CA,B,C} = \underline{R}_{CA,B,C} + j\underline{X}_{CA,B,C} \qquad (3.4)$$

$$\underline{Z}_{cab} = \underline{R}_{cab} + j\omega\underline{L}_{cab} \qquad (3.5)$$

We obtain the passing currents in the three phases from the previous equation according to three currents at the secondary of the transformer:

$$\begin{cases} \underline{I_{CA}} = \dfrac{\underline{V_A} + \underline{I_A}.\underline{Z_{cab}} + \dfrac{\left(\underline{I_A} - \underline{I_B}\right)\underline{Z_{cab}}}{\underline{Z_{CA}}.\underline{Z_{cab}}} + \dfrac{\underline{V_A} - \underline{V_C} + \left(\underline{I_A} - \underline{I_C}\right)\underline{Z_{cab}}}{\underline{Z_{CC}}.\underline{Z_{cab}}}}{\underline{Z_{cab}} + \dfrac{\underline{Z_{CA}}.\underline{Z_{cab}}}{\underline{Z_{CB}}} + \dfrac{\underline{Z_{CA}}.\underline{Z_{cab}}}{\underline{Z_{CC}}} + \underline{Z_{CA}}} \\ \underline{I_{CB}} = \dfrac{\underline{V_A} - \underline{V_B} + \left(\underline{I_A} - \underline{I_B}\right)\underline{Z_{cab}} + \underline{I_{CA}}.\underline{Z_{CA}}}{\underline{Z_{CB}}} \\ \underline{I_{CC}} = \dfrac{\underline{V_A} - \underline{V_C} + \left(\underline{I_A} - \underline{I_C}\right)\underline{Z_{cab}} + \underline{I_{CA}}.\underline{Z_{CA}}}{\underline{Z_{CC}}} \end{cases} \qquad (3.6)$$

8) ***Four-arm inverter***

Using the four-arm inverter with MLI control, we have another relationship between the average compound voltages and the output voltages of the four-arm inverter:

$$\begin{cases} \underline{V_A} - \underline{V_B} + \left(\underline{D_1} - \underline{D_2}\right).U_{dc} + \left(2\underline{I_A} - \underline{I_{CA}} - 2\underline{I_B} + \underline{I_{CB}}\right).\underline{Z_{ond}} = 0 \\ \underline{V_C} - \underline{V_A} + \left(\underline{D_3} - \underline{D_1}\right).U_{dc} + \left(2\underline{I_C} - \underline{I_{CC}} - 2\underline{I_A} + \underline{I_{CA}}\right).\underline{Z_{ond}} = 0 \\ \underline{V_A} + \left(\underline{D_4} - \underline{D_1}\right).U_{dc} - \left(-2\underline{I_A} + \underline{I_{CB}} + \underline{I_{CC}} + 2\underline{I_{CA}}\right).\underline{Z_{ond}} = 0 \end{cases} \quad (3.7)$$

From the equation, we can determine the relationship between cyclic ratios to control switches

$$\begin{cases} \underline{D_2} = \underline{D_1} - \left(\frac{\underline{V_A} - \underline{V_B}}{U_{dc}} + \frac{\left(2\underline{I_A} - \underline{I_{CA}} - 2\underline{I_B} + \underline{I_{CB}}\right) . \underline{Z_{ond}}}{U_{dc}} \right) \\ \underline{D_3} = \underline{D_1} - \left(\frac{\underline{V_C} - \underline{V_A}}{U_{dc}} + \frac{\left(2\underline{I_C} - \underline{I_{CC}} - 2\underline{I_A} + \underline{I_{CA}}\right) . \underline{Z_{ond}}}{U_{dc}} \right) \\ \underline{D_4} = \underline{D_1} - \left(\frac{\underline{V_A}}{U_{dc}} - \frac{\left(-2\underline{I_A} + \underline{I_{CB}} + \underline{I_{CC}} + 2\underline{I_{CA}}\right) . \underline{Z_{ond}}}{U_{dc}} \right) \end{cases} \quad (3.8)$$

Where $\underline{Z}_{ond}$ is the impedance of the UPS filter ($\underline{Z}_{ond} = R_{ond} + j\omega L_{ond}$).

9) Three-arm currents

Here, the role of the four-arm inverter is to distribute the unbalanced currents in the charges, i.e. the active power of the charges has not changed when the four-arm inverter is connected to the secondary of the transformer. The set currents of the three phases are functions of the active loads powers. They are offered below:

$$P_{res} = \frac{3. I_M . U_{nom}}{\sqrt{2}} = P_A + P_B + P_C \quad (3.9)$$

Where: P_A, P_B and P_C are the power of three charges and U_name is the nominal voltage of the network

$$I_M = \frac{\sqrt{2}\,(P_A + P_B + P_C)}{3. U_{nom}} \qquad (3.10)$$

D. Dimensioning of the four-arm MLI inverter

10) Nominal capacity

We study the design capacity of the four-arm inverter with different loads. Here we need to determine the current currents in the four-arm inverter switches. The equations allow us to calculate these currents according to the charges:

$$\underline{I'}_A = \underline{I}_A - \underline{I}_{CA} \qquad (3.11)$$

$$\underline{I}_A + \frac{\underline{V_A} + \underline{I_A}.\underline{Z}_{cab} + \frac{\underline{V_A} - \underline{V_B} + (\underline{I_A} - \underline{I_B})\underline{Z}_{cab}}{\underline{Z}_{CA}.\underline{Z}_{cab}} + \frac{\underline{V_A} - \underline{V_C} + (\underline{I_A} - \underline{I_C})\underline{Z}_{cab}}{\underline{Z}_{CC}.\underline{Z}_{cab}}}{\underline{Z}_{cab} + \frac{\underline{Z}_{CA}.\underline{Z}_{cab}}{\underline{Z}_{CB}} + \frac{\underline{Z}_{CA}.\underline{Z}_{cab}}{\underline{Z}_{CC}} + \underline{Z}_{CA}} \quad (3.12)$$

Similarly, currents passing through switches in other arms can determine:

$$\underline{I'}_B = \underline{I}_B - \underline{I}_{CB} \qquad (3.13)$$

$$\underline{I'}_C = \underline{I}_C - \underline{I}_{CC} \qquad (3.14)$$

$$\underline{I'}_N = \underline{I}_N = \underline{I}_{CA} + \underline{I}_{CB} + \underline{I}_{CC} \qquad (3.15)$$

11) Sine-like stresses and currents

When tension and currents are sinusoidal, it is always possible to write the instantaneous power of the three-phase network in the time domain:

$$p(t) = v_A(t)x\, i_A(t) + v_B(t)x\, i_B(t) + v_C(t)x\, i_C(t) \quad (3.16)$$

By introducing the symmetrical components (direct, indirect and homopolar) of the voltage and current systems, the instantaneous power becomes:

$$\underline{p} = 3x\left(\underline{V_d}x\,\underline{I^*{}_d} + \underline{V_i}x\,\underline{I^*{}_i} + \underline{V_h}x\,\underline{I^*{}_h} + \left(\underline{V_d}x\underline{I_d} + \underline{V_i}x\underline{I_i} + \underline{V_h}x\underline{I_h}\right)xe^{j2\omega t}\right) (3.17)$$

Where:

V_{dih} :direct, indirect and homopolar complex voltage

I_{dih} :direct, indirect and homopolar complex currents

$I^*{}_{dih}$:complex currents conjugate direct, indirect and homopolar.

12) Instant power

The instantaneous power using the symmetric components is split into two parts: fluctuating power and apparent power. They write as :

$$\underline{P}_{fthuc} = 3x\left(\underline{V_d}x\underline{I_d} + \underline{V_i}x\underline{I_i} + \underline{V_h}x\underline{I_h}\right)xe^{j2\omega t} \quad (3.18)$$

$$\underline{S} = 3\,x\left(\underline{V_d}x\,\underline{I^*{}_d} + \underline{V_i}x\,\underline{I^*{}_i} + \underline{V_h}x\,\underline{I^*{}_h}\right) \quad (3.19)$$

13) Balanced currents at secondary level

Because when the three currents in the secondary are balanced, the transformer generates a power corresponding to the apparent power. It is expressed by the following equation :

$$\underline{S_C} = 3x\left(\underline{V_{dres}}x\,\underline{I^*{}_{dres}} + \underline{V_{ires}}x\,\underline{I^*{}_{ires}} + \underline{V_{hres}}x\,\underline{I^*{}_{hres}}\right) \quad (3.20)$$

where

$\underline{S_C}$: the apparent load power part

$\underline{V}_{dihc}, \underline{V}_{dihres}$:
complex direct, indirect and homopolar load and netwo rk stresses.

$I^*{}_{dnic}, I^*{}_{dhires}$:
the complex currents conjugated directly, indirectly and homopolar and those of the network.

The equations defining the complex stresses of the load s are :

$$\underline{V}_{dc} = \frac{1}{3} x\ (V_{CA} + a\ x\ V_{CB} + a^2 x\ V_{CC}) \quad (3.21)$$

$$\underline{V}_{ic} = \frac{1}{3} x\ (V_{CA} + a^2\ x\ V_{CB} + a\ x\ V_{CC}) \ (3.22)$$

$$\underline{V}_{hc} = \frac{1}{3} x\ (V_{CA} +\ V_{CB} +\ V_{CC}) \quad (3.23)$$

With

$$a = -\frac{1}{2} + jx\frac{\sqrt{2}}{2} \qquad (3.24)$$

We use similar expressions to calculate network and loa d voltages and currents. For the rest of the load power, the four-arm inverter will absorb this fluctuating power to elimi nate the alternative part. This fluctuating power is expr essed as :

$$\underline{P}_{fthuc} = 3x\left(\underline{V_{dond}} x \underline{I_{iond}} + \underline{V_{iond}} x \underline{I_{dond}} + \underline{V_{hond}} x \underline{I_{hond}}\right) x e^{j2\omega t} \quad (3.25)$$

Where :

$\underline{P}_{fthuc}$: The fluctuating load power

$\underline{V}_{dihond}$:
the complex direct, indirect and homopolar voltages of the inverter

$\underline{I}_{hond}$:
the direct, indirect and homopolar complex currents of the inverter.

14) ***Voltage drop***

The voltage drop of the inverter is neglected w hen connected to the secondary transformer. Th e UPS voltage is therefore:

$\underline{V}_{dihond} = \underline{V}_{dihres}$

The fluctuating load power can be described as follows:

$$\underline{P}_{fthuc} = 3\ x\ \underline{V}_{dres}\ x\ \underline{I}_{iond}\ \ x\ e^{j2\omega t} \quad (3.26)$$

To provide this fluctuating power, the inverter must be able to deliver more power than this apparent power

$$S_{ond} = V_{dres}\ x\ I_{iond} \qquad (3.27)$$

For data from three charges, the indirect current of the inverter can be determined by considering equations (4. 49) and (4.50). It reads as follows :

$$\underline{I}_{iond} = \frac{1}{3} x\left(\underline{I}_A{}' + a^2\ x\ \underline{I}_B{}' + ax\ \underline{I}_C{}'\right) \Rightarrow (3.28)$$

$$\underline{I}_{iond} = \left(\underline{I}_A - \underline{I}_{CA} + a^2 x\left(\underline{I}_B - \underline{I}_{CB}\right) + ax\left(\underline{I}_C - \underline{I}_{CC}\right)\right) \ (3.29)$$

IV. Application to Homopolistic Imbalance

A. Load-dependent

To illustrate our point, we use a numerical example where the charges are unbalanced:

- The loads : $P_a = 10\ kW$; $P_b = 15\ kW$; $P_c = 3{,}5\ kW$
- The amplitude of the set current: $I_M = \frac{\sqrt{2}\,(P_A+P_B+P_C)}{3.U_{nom}} = 35\ (A)$

Filter Inductance : $L_{ond} = 7{,}5\ x\ 10^{-3} (H)$; $R_{ond} = 0{,}001\ (\Omega\,)$

- Condensaor : $C_{dc} = 75\ (\mu F)$; $U_{dc} = 600\ (V)$
- Switch strength : $R_{on} = 0{,}001\ (\Omega\,)$
- Transformer secondary cable $R_{cab} = 0{,}05\ (\Omega\,)$; $L_{cab} = 0{,}0005\ (H\,)$

B. Matlab/simulink model

The numerical simulation model developed under MATLAB/Simulink is shown in Figure 3. The mod el is constructed using the equivalent model of a thr ee-phase inverter.

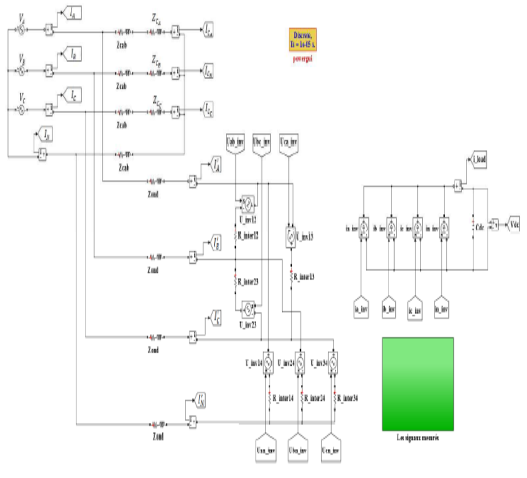

Fig. 3 Model of the four arm balancer and the isolated neutral network in MATLAB/Simulink

V. CONCLUSIONS

In this paper, we demonstrated with detailed math ematical models that the performance of a static co mpensator (or a fourarm inverter). One of the advantages of our method is to directly determine the cyclic ratios in order to control the trim switches.

We have thus shown the relevance of this solution is that its dimensioning is directly proportional to the reverse current absorbed by the unbalanced loads. Future work will focus on non-linear loads, i.e. harmonics are taken into account in the sizing of the compensator.

In highly unbalanced networks, it is not easy to meet contractual and regulatory obligations. In order to carry out network studies, the operator must be able to use computer tools using models that take account of single phase load asynchronism. It should also, where possible, give preference to three-phase connection for highly unbalanced loads.

It can also connect customers highly charged and unbalanced by dedicated lines while ensuring the quality of the neutral driver.

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