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STUDY OF REACTIVE POWER COMPENSATION BY CAPACITOR BANKS IN THE INDUSTRIAL COMPLEX OF THE N'DJILI WATER DISTRIBUTION AUTHORITY (REGIDESO N'DJILI), CITY OF KINSHASA

[1]Sibitali Aukawa Stéphane, [2]Mbila Mokondo Roger, [3]Buetham Mbidika Benny, [4]Ekaa Louis, [5]Mfulu Mawete Arnauld, [6]Nzau Umba-Di-Mbudi Clement

[1]Research enginneer, [2]Enginneer, [3]Research engineer, [4]Research engineer, [5]Research engineer, [6]Full professor
[1]Energy engineering and environment,
[1.2.3.4.5]University of Kinshasa, Faculty of Oil, Gas and Renewable Energy, Kinshasa, Democratic Republic of Congo
[6]University of Kinshasa, Faculty of science and technology, Kinshasa, Democratic Republic of Congo

Abstract: Our study offers an economical and adapted solution to improve the electrical quality of an industrial complex. The choice of which capacitor banks to install depends on several factors, such as the total active power of the installation, the cosine phi and tangent phi power factors before and after the installation of the capacitors, as well as the total installed apparent power. Using data from the industrial complex's inductive receivers and making some assumptions, we determined the total active, reactive, and apparent power using CALCELECT 2.1.0 software for 24 hours of use. Taking into account the simultaneity factor KS per number of receiver, we obtained the following values: 4757.45 KW of active power, 2826.34 KVAR of reactive power and 5533.67 KVA of apparent power, with a power factor of 0.865. The implementation of compensation by capacitor banks, in accordance with the conditions of the REGIDESO N'DJILI industrial complex, requires an investment of approximately $110,000. Currently, REGIDESO SA spends on average $43,200 per year in penalties linked to poor power factor. Thanks to this solution, the investment will be recovered in less than 3 years. In addition, with an estimated lifespan of between 10 and 12 years for the proposed capacitor banks, REGIDESO SA will save at least $432,000 over the next 10 years.

***Key words*: reactive power compensation, cosine phi, active power, capacitor banks**

1. INTRODUCTION

Numerous studies show that global energy demand is expected to double by 2050. The proliferation of production plants can lead to significant economic and environmental impacts, hence the need to use energy more efficiently and reduce your consumption. Industrial and residential buildings represent more than half of the world's energy needs, requiring us to find new solutions to improve energy efficiency in our homes and industries by integrating innovations, modern control and measurement tools, as well as adopting alternative renewable energy sources.

Preserving natural resources is a fundamental objective, and improving energy efficiency is one of the main objectives of international energy policies. Reactive energy compensation in industrial buildings is one of the different methods to increase energy efficiency. Indeed, the use of reactive energy compensation equipment offers savings opportunities and arrangements that can immediately and significantly reduce energy consumption.

The uncontrolled circulation of reactive energy in the coils of motors and other inductive loads poses a significant technical and economic problem in many medium and large power electrical installations. Excess reactive energy in a large industrial installation, such as the REGIDESO N'DJILI industrial complex, contributes to a decrease in the power factor, which is taken into account during electricity billing, as well as an increase in the current demand, heating of power cables, additional losses, significant voltage drops, overloads at the level of transformers and oversizing of installations.

Many medium and large power customers of the National Electricity Company "SNEL SA" are therefore subject to significant penalties due to a poor power factor of their installation. Indeed, in addition to active and reactive energy consumption, SNEL SA applies an increase to monthly billing for electrical installations with a power factor (cos φ) less than 0.95. In order to avoid penalties imposed by SNEL SA, it is essential to increase the power factor to 0.95 or more. This increase can be achieved by compensating the reactive energy produced by the inductive loads of the installation. Industrial reactive energy compensation is a process aimed at reducing the harmful effects of reactive energy generated by inductive loads in industrial installations.

The power factor is an indicator of the quality of design and management of an electrical installation. It is based on two very fundamental notions: active power and apparent power. Improving the power factor of an installation has numerous economic and technical advantages. On an economic level, its improvement makes it possible to reduce the electricity bill, and on a technical level, it makes it possible to reduce energy losses by the Joule effect (by reducing the intensity in the conductors upstream of the compensation system), to reduce voltage drops at the end of the line and, in certain cases, to increase the active power available for the same installation.

2. METHODOLOGICAL APPROACH

2.1. Presentation of the site

The REGIDESO N'DJILI complex is located in the city Kinshasa in the Democratic Republic of Congo (DR Congo), a country bordering Congo Brazzaville.

The factory and the catchment point are located respectively on the longitude of 15.356187 decimal degree and a latitude of -4.377826 decimal degree and on the longitude of 15.365713 decimal degree and a latitude of -4.386801 decimal degree. The plant and the catchment point are separated by a distance of 1820 meters.

The catchment point is located approximately 20 meters from the N'DJILI River, at the intersection of the N'DJILI River and Lumumba Boulevard in the commune of LIMETE as shown in Figure 1. The N' factory DJILI is located at the 17th [heavy] goods street in the NDALU district in the commune of LIMETE, behind SAFRICAS company.

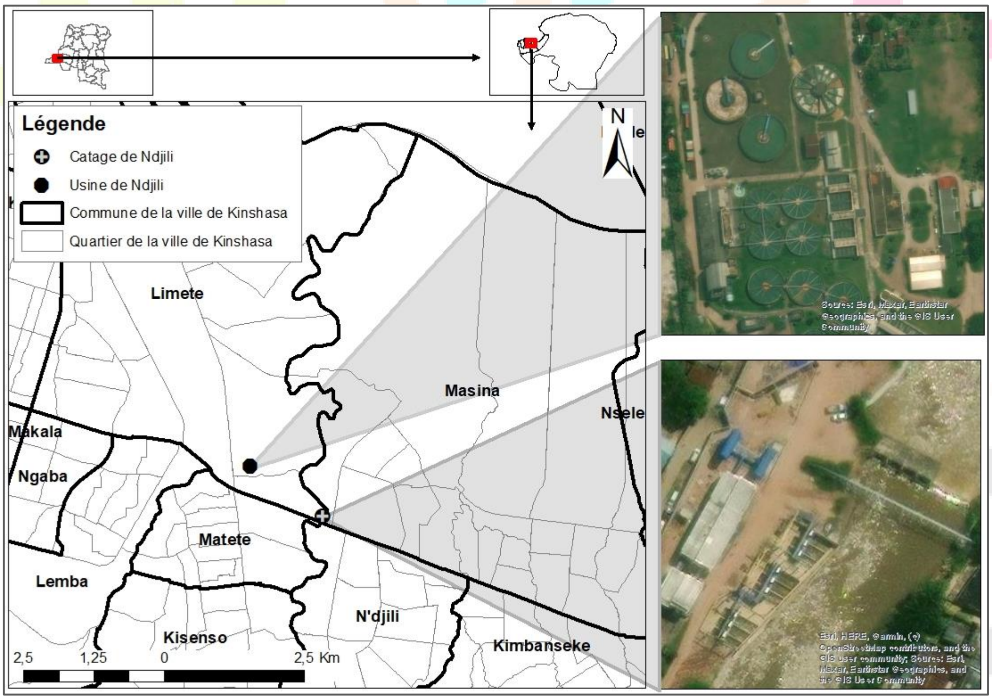


Figure 1. Cartographic representation of the REGIDESO N'DJILI industrial complex

For its normal operation, the REGIDESO N'DJILI catchment mainly includes the following hydraulic structures and electromechanical equipment:

- A blocade
- Grit collectors
- A machine room, equipped with eight motor pump units which operate with an average voltage of 6600V
- A machine control room has a transformer for the auxiliaries, medium-voltage incoming cells, remote control consoles for the eight pump sets and a general low-voltage panel.

Regarding water treatment in the Factory, the industrial complex is made up of three factories called Module 1, 2 and 3, as well as a water discharge room:

- Plant 1 is supplied by three main lines. Its medium voltage part is used for the electric motors for delivery to the other processing module, and its second part is used for the auxiliaries.

- Factory 2, with a production capacity of 110,000 m3/day, is located southeast of the industrial complex, approximately 10 meters from factory 3. Unlike factory 1, which has two transformers of 315 KVA for its low voltage part, factory 2 only has one with a capacity of 400KVA.
- The 6600 V medium voltage feeders supply plant 3, which is equipped with two 400KVA low voltage transformers, one of which is connected to the network and the other serves as a backup in the event of a breakdown of the first. However, medium voltage is converted to low voltage, which is divided into 16 main circuits.

2.2. Methods

2.2.1. Documentary studies

For this research method, we collected information from books, various written documents such as electricity bills, articles, reviews and posts on websites. This allowed us to deepen our understanding of the research topic.

2.2.2. Data collection and analysis

Data collection began with the acquisition of the factory's electrical subscription information from invoices from the company SNEL SA, after confirmation of the penalties due to the incorrect power factor. Next, a field visit was carried out to identify machines and devices that could generate reactive energy, which could harm the factory's network and electrical installations. Once these machines were identified, the operating characteristics were collected.

2.2.3. Data processing

Field data collection made it possible to determine correction factors such as the maximum utilization factor (Ku), the simultaneity factor (Ks) and the expansion factor (Ke). The information collected in the field also made it possible to estimate the total active, reactive and apparent power of the installation.

2.2.4. Methods for sizing capacitor banks

The sizing of the capacitor banks was carried out using the data collected during the previous stages, in order to design a reactive energy generation system to be injected into the installation to neutralize that produced by the various receivers of the industrial complex. The reactive power QC necessary for compensation is calculated from the total active power and the power factor (tan φ) of the installation.

2.2.5. Distribution of electrical energy to the REGIDESO N'DJILI complex

The REGIDESO N'DJILI industrial complex receives its electrical energy supply from the National Electricity Company (SNEL SA). The SNEL LIMINGA substation supplies the REGIDESO N'DJILI electrical substation via two 30 KV voltage lines, both underground and overhead. The delivery station has an installed power of 11 MVA and is equipped with two 30/6.6 KV transformers, one of which is reserve. If necessary, these transformers can be coupled in parallel and are individually protected upstream and downstream by medium voltage circuit breakers. The 30 KV part powers the transformers, while the 6.6 KV part powers each module individually.

In order to ensure optimal continuity of service, the REGIDESO N'DJILI industrial complex has set up a double branch electrical energy distribution system. This system allows you to switch to an alternative line in the event of failure of the other. Although the two arrivals come from different sources, they may come from the same source. However, the simultaneous connection of the two inlets is prevented by a mechanical interlock. The second arrival can be powered by a diesel generator, gas or a set of photovoltaic modules.

In the REGIDESO N'DJILI complex, nine departures have been installed. Feeds 1 to 4 are used for measurements, feeds 5 and 6 are dedicated to the collection point, while feeds 7, 8 and 9 are respectively intended for plants 1, 2 and 3. Each plant feed is supplied by a voltage of 6600V. At the catchment point, two transformers of 100 KVA each are installed in parallel, while in plant 1, two transformers of 315 KVA each are also installed in parallel. Within the premises of Plant 2 and Plant 3, two and one transformer of similar capacity of 400 KVA respectively are installed.

3. RESULTS AND ANALYZES

This section deals with the power balance of the sensitive receivers of the REGIDESO N'DJILI industrial complex by two calculation methods, analytical and by the CALCELCT 2.1.0 software; sizing the necessary capacity of the capacitor bank to be installed on the industrial site and then estimating the cost of the project

3.1. Presentation of data collection and analysis results

N'DJILI industrial complex includes several sensitive receivers, and their power was evaluated using two calculation methods: analytical and with the CALCELC 2.1.0 software. In addition, the dimensioning of the necessary capacity of the capacitor bank to be installed on the industrial site was carried out, as well as the estimation of the cost of the project.

The N'DJILI catchment, there are eight motor pump units used to pump water to the factory. Of these eight groups, six operate permanently, while the other two are in reserve. For the power balance, we will only consider the six groups in operation. Table 1 presents the characteristics of the catchment pump sets.

Table 1. Installed capture power

Receivers	**Voltage (V)**	***cos φ***	**Rated Power (KW)**	**Current (A)**
6 ABB Motor Pump Groups	66OO	0.81	450	51
15 Philips Tubes (TL-D)	-	1	0.051	
Total			**2700**	

Table 2 shows the most sensitive receptors in the discharge room. The nine discharge pump units operate continuously.

Table 2. Installed discharge power

Receivers	**Voltage (V)**	***cos φ***	**Rated Power (KW)**	**Current (A)**
7 ABB Motor Pump Groups	6600	0.88	700	72
2 SIEMENS Motor Pump Groups	6600	0.87	855	90
24 Philips Tubes (TL-D)	-	1	0.036	
Total			**6610**	

Plant 1 or module 1 includes receivers operating at low voltage, as shown in Table 3.

Table 3. Factory installed power 1

Receivers	**Voltage (V)**	***cos φ***	**Rated Power (KW)**	**Current (A)**
2 Motors for filter washing	400	0.77	22	45.5
2 Booster motors	400	0.90	90	161
3 Motors for sulfate dosing	400	0.74	0.75	1.8
4 Motors for lime dosing	400	0.5	0.25	0.8
10 Motorcycle agitator groups	400	0.69	0.37	1.12
10 Philips Tubes (TL-D)	400	1	0.036	
TOTAL			**230, 9**	

Most of the receivers in Factory 2 are the same type as those in Factory 1, as shown in Table 4.

Table 4. Factory installed power 2

RECEIVERS	**VOLTAGE (V)**	**cos φ**	**RATED POWER (KW)**	**CURRENT (A)**
2 MOTORS FOR FILTER WASHING	400	0.90	15	28
2 BOOSTER MOTORS	400	0.90	90	161
3 MOTORS FOR SULFATE DOSING	400	0.74	0.75	1.8
4 MOTORS FOR LIME DOSING	400	0.5	0.25	0.8
10 MOTORCYCLE AGITATOR GROUPS	400	0.69	0.37	1.12
8 PHILIPS TUBES (TL -D)	400	1	0.036	
TOTAL			**216, 9**	

Table 5. Lists factory 3 receivers, which are similar to those of previous factories.

RECEIVERS	**VOLTAGE (V)**	**cos φ**	**RATED POWER (KW)**	**CURRENT (A)**
3 MOTORS FOR FILTER WASHING	400	0.85	30	56
2 BOOSTER MOTORS	400	0.90	90	161
2 MOTORS FOR SULFATE DOSING	400	0.74	0.75	1.8
2 MOTORS FOR LIME DOSING	400	0.5	0.25	0.8
24 MOTORCYCLE AGITATOR GROUPS	400	0.69	0.37	1.12
10 PHILIPS TUBES (TL -D)	400	1	0.036	
TOTAL			**280, 8**	

3.2. Analysis of compensation on site electricity billing

3.2.1. Analysis before compensation

Before analyzing the effect of compensation on the site's electricity billing, let's look at how the billing is calculated. The invoice calculation formula is given by the following equation:

$$F = (A \times B) + (B \times C) \quad (1)$$

Or:

F: Represents the invoice amount in Congolese Francs;
A: Represents the fee per kilowatt of subscribed power;
P: Represents the subscribed power in kilowatts;
B: Represents the fee in kilowatt-hours of electrical energy in Congolese Francs;
C: Represents monthly consumption in kilowatt-hours.

The term A explicitly represents the part related to power. If the subscribed power (PS) is greater than the peak power (PP), the subscribed power is taken into account. (Source: REGIDESO N'DJILI operating service)

On the other hand, if the peak power is greater than the subscribed power, the power to be billed is calculated as follows:

$$PS + [(PP - PS) \times 1{,}5] \quad (2)$$

The term B represents the part linked to consumption and is calculated as follows:

$$HU = \frac{C}{PS} \quad (3)$$

We can express the term B as follows:

$$B = HU \times PF \quad (4)$$

Or:

HU: Hour of use;

PF: Power to be billed;

C: Monthly consumption (average consumption)

The power fee is invoiced based on the subscribed power and a fixed premium. The fixed premium is a billing parameter for the subscribed power, and its annual evolution is determined by the electricity supplier.

The term A is expressed by:

$$TA = A \times P \quad (5)$$

And the term B by:

$$TB = B \times C \quad (6)$$

The fee per kilowatt of subscribed power A was Congolese Francs in 2022 10 185,25 FC(Congolese Francs) or $4.96 USD (With 1$ USD = 2054.77 FC), and the fee per kilowatt-hour of electrical energy B was 140 .2909 FC (Congolese Francs), or $0.07 USD.

$$TA = 10185.2479 \times 6150 = \mathbf{62\ 639\ 274.61}\ FC\ soit\ \mathbf{30\ 484,69}\ \$$$

$$TB = 140.2909 \times 2\ 694\ 000 = \mathbf{377\ 943\ 684.6\ FC}\ soit\ \mathbf{183\ 934,05}\ \$$$

In addition to this, surcharges for bad cosine phi, rental of MV meters, public lighting and value added tax are added to the billing. In this case, the total invoice amount will be 531,020,465 Fc (Congolese Francs) or $258,432.00 USD, as shown in Figure2.


Société Nationale d'Electricité, SA
Date d'édition 29/12/2022 1008 - 956
FMT 6012212481482/04
FACTURE D'ENERGIE ELECTRIQUE MOYENNE TENSION Décembre 2022
méro Impôt A0700177B
ntrat : 68-441
om : REGIDESO CAPTAGE N'DJILI
dresse : 1, Rue 18EME RUE INDUSTRIEL, LIMETE
Type Client : 25 SOCIETES PARAETATIQUES
Tarif COMMERCIAL
Cabine REGIDESO N'DJILI CAPTAGE
Date de dépôt

Compteur Type	Numéro	Index Précédent	Index Actuel	Difference	Coefficient	Constante	Consommation
Triphasé	000002283115	193143	195837	2694	1 000,0000	1,0000	2694000
Réactif	000068441049	111860	113254	1394	1 000,0000	1,0000	1394000

Somme CTRS Monophasés 0 Kwh
Somme CTRS Décompte 0 Kwh
Moyenne à Facturer 2694000 Kwh
Tangente Phi 0,52
Cosinus Phi 0,89
Quart Horaire 6,0100
Puissance Souscrite 6150 Kw
Puissance de Pointe 6010 Kw
CAUTION Facturée Déjà Payée
Heure d'utilisation 438,05 438,05
Puissance Facturée 6150

Terme A	62 639 274,81
Terme B	377 943 813,98
Majoration pour mauvais Cosinus Phi	13 217 492,66
Réactualisation Caution	0,00
Pénalité pour refus d'accès	0,00
Indemnisation de vos Installations	0,00
Location Compteur MT	63 061,07
Eclairage Publique (1%)	4 538 636,42
Taxe sur la Valeur Ajoutée	72 618 182,77
Redevance	0,00
Total facture du mois	531 020 465,00 $258 432,00

REGIDESO DPK
Enregistrement 2084/2759
Réf. Document
Nature Document
Reçu le 05/01/2023
N° Indicateur
Transmis à
Répondu le

Montant de la facture
531 020 465,00 CDF
$258 432,00

Le montant de cette facture est exigible dans 8 jours; passé ce délai, la S.N.EL, SA procédera au recouvrement forcé de la créance.

AVIS DEPASSE LE DELAI REGLEMENTAIRE DE 8 JOURS, LA VALEUR EN USD DE CETTE FACTURE EST PAYABLE EN CDF AU TAUX DU JOUR.

Société Nationale d'Electricité, SA
COUPON REGLEMENT (Reservé à la SNEL)
Date d'édition 29/12/2022
Caisse : MOYENNE TENSION
Contrat : 68-441
Nom REGIDESO CAPTAGE N'DJILI
Numéro Facture FMT 6012212481482/04
Montant à payer 531 020 465,00
$258 432,00
Société Nationale d'Electricité SA, RCCM N° CD/KIN/RCCM/14-B-3326, ID NATIONALE A 3970 O, N° IMPOT : A0704644G, 2831 Avenue de la justice

Figure 2. Medium voltage (MT) bill December 2022 for the REGIDESO N'DJILI complex in the city of Kinshasa by the electricity company SNEL SA

3.2.2. Billing penalty

The penalty consists of overbilling by the SNEL company when the contract with the customer is not respected. Regarding the penalty linked to the wrong cosine phi, the monthly bill is increased by a penalty of 1% per hundredth of a cosine less than 0.95 for the first ten hundredths, and of 2% per hundredth of a cosine less than 0 .80. SNEL also applies extra billing when the number of hours of use exceeds the theoretical number of hours. In this case, the billed power is equal to the average billed consumption divided by the number of hours for the month, i.e. 720 hours for 30 days or 744 hours for 31 days. [7]

3.3. Determination of the total active, reactive and apparent power of the installation

3.3.1. Determination of the total powers of the installation by the analytical method

To calculate the total power of the installation, it is necessary to multiply the total power absorbed by the simultaneity and extension factors specific to each panel.

Not all receivers in an installation operate simultaneously. This is why it is possible to apply simultaneity factors to different sets of receivers or circuits. Determining these simultaneity factors requires detailed knowledge of the installation considered and experience of operating conditions, particularly for motors and power outlets. It is therefore not possible to provide precise values applicable to all cases, as shown in Table 7.

Also called reserve factor, its role is to provide for an increase in the power absorbed by the company in the future, which must not exceed 20% of the total apparent power according to the standards in force. The reserve factor coefficient generally ranges from 1 to 1.5. [8]

Table 6. Simultaneity factor depending on the number of receivers (Source: NF C 14-100, NF C 63-410 standards and the UTEC 15-105 guide)

Number of receivers	Simultaneity factor Ks
1 to 3	0.9
4 to 5	0.8
5 to 9	0.7
10 and above	0.5

$$P_{totale} = \sum P_a \times K_S \times K_{ext} \quad (7)$$

$$Q_{totale} = \sum Q \times K_S \times K_{ext} \quad (8)$$

$$S_{totale} = \sqrt{P_{totale}^2 + Q_{totale}^2} \quad (9)$$

To calculate the general powers of the installation, it is necessary to multiply the total power obtained at the level of the secondary distribution panels by the simultaneity factor corresponding to the general panel. Then, we add the value of the extension factor (Kext).

Table 8 presents the total active, reactive and apparent powers of the installation without taking into account simultaneity and extension factors. Table 9 shows the results of the power balances taking these factors into account (see relationships 7, 8 and 9).

Table 7. Total active, reactive and apparent power of the installation

	P_a *totale* (KW)	Total Q (KVAR)	Total S (KVA)	$\cos\varphi$	$\tan\varphi$
Capture	2132.32	1534.74	2,627.2	0.81	0.72
Repression	5178.95	2,823.17	5898.45	0.88	0.54
Factory 1	195.21	110.43	224.28	0.86	0.59
Factory 2	185.04	92.89	234.7	0.88	0.54
Factory 3	237.6	130.85	271.25	0.87	0.57
TOTAL	**7929.12**	**4,692.09**	**9213.39**	**0.86**	**0.59**

Table 8. Total active, reactive and apparent power of the installation as a function of Ks and Kext (P total)

	K_s	K_{ext}	P_a *totale* (KW)	*Total Q (KVAR)*	*Total S (KVA)*	$\cos\varphi$	$\tan\varphi$
Capture	0.6	1	1279.39	920.84	1576.32	0.81	0.72
Repression	0.6	1	3107.37	1,693.9	3539.07	0.88	0.54
Factory 1	0.6	1	117.13	66.26	134.57	0.86	0.59
Factory 2	0.6	1	111.02	55.73	124.22	0.88	0.54
Factory 3	0.6	1	142.56	78.51	162.75	0.87	0.57
TOTAL			**4757.47**	**2815.24**	**5528.03**	**0.86**	**0.59**

3.3.2. Determination of the total power of the installation using the CALCELECT software

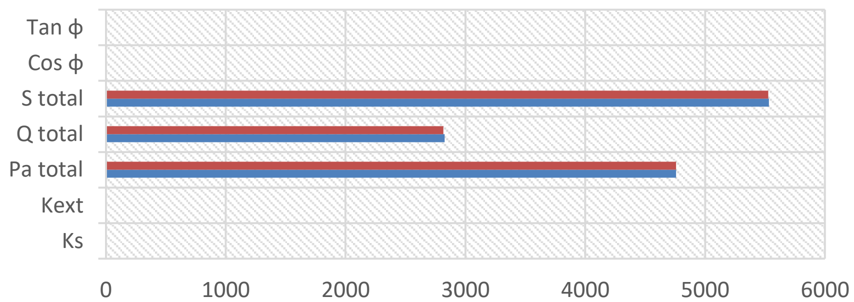
The CALCELECT software allows you to perform these calculations of power, current, voltage, and other electrical parameters. The results are presented clearly and concisely in Table 9.

Table 9. Total active, reactive and apparent power of the installation as a function of Ks and Kext (P_total) by CALCELECT

	K_s	K_{ext}	P_a *totale* (KW)	Total Q (KVAR)	Total S (KVA)	$\cos\varphi$	$\tan\varphi$
Capture	0.6	1	1279.406	925,942	1579.319	0.810	0.724
Repression	0.6	1	3107,393	1698.770	3541,428	0.877	0.548
Factory 1	0.6	1	117,114	66,606	134,729	0.869	0.569
Factory 2	0.6	1	111,010	56,179	124,416	0.892	0.507
Factory 3	0.6	1	142,525	78,840	162,877	0.875	0.553
TOTAL			**4757.45**	**2826.34**	**5533.67**	**0.865**	**0.580**

3.3.3. Comparison of the results of these two calculation methods

The comparative representation between the analytical and software calculation method is illustrated in Figure 3.



	Ks	Kext	Pa total	Q total	S total	Cos ϕ	Tan ϕ
Analytical method	0.6	1	4757.47	2815.24	5528.03	0.86	0.59
CALCELECT Software	0.6	1	4757.45	2826.34	5533.67	0.865	0.58

Analytical method   CALCELECT Software

Figure 3. Comparisons of power balance results

Comparison of the results of the two calculation methods suggests that the power balance by CALCELECT gives an almost identical active power result, with a difference of a few decimal places, compared to the power balance by the analytical method. The differences observed mainly concern the reactive power and the cosine phi power factor. These differences are attributable to the fact that the CALCELECT software takes into account several parameters, such as the starting current - rated current ratio for low power motors, also called limiting coefficient Id/In, as well as the power factor at starting of each receiver.

3.4. Choice of capacitor banks to install

For a specific installation, the choice of capacitor banks to install involves determining the power Qc of the batteries, locating the appropriate installation area and choosing the appropriate type of installation. The power of the capacitors Qc is determined by taking into account the total active power measured or defined, as well as the power factor (tangent phi) of the installation.

The reactive power of the capacitors to be installed is calculated using the following relationship:

$$Q_C = P \times (\tan\varphi - \tan\varphi') \tag{10}$$

Or :

P is the total active power of the installation.
$\tan\varphi$:Phi tangent of the installation before compensation.
$\tan\varphi'$:Desired phi tangent after compensation.

In our case, we want to bring the plant power factor from 0.865 to 0.95 to avoid the penalties associated with poor cosine phi. Thus, for a cosine phi of 0.95, the tan φ to reach will be 0.328.

$$Q_C = 4757{,}45 \times (0{,}580 - 0{,}328) = \mathbf{1\,199{,}27\ Kvar}$$

3.5. Determining the type of compensation

To determine the choice of the compensation system we must check that the battery power to be installed is higher or lower than the installed power of the installation (transformer power).

For our case, the installed power of the installation transformer is 11 MVA. Installation can be fixed or automatic. So we must check if the capacitor power to be determined above is less than or greater than 15% of the installed power. [15]

To determine 15% of the installed power, take 11 MVA or 11000 KVA multiplied by 15/100.

$$11000\ KVA \times \frac{15}{100} = \mathbf{1{,}650} > \ 1255{,}96\ Kvar$$

Hence, automatic global compensation is not appropriate for our installation.

3.6. Determination of compensation location

Following the results obtained previously concerning the type of compensation, we must opt for local compensation, that is to say, install the batteries in each secondary installation (catchment; discharge; plant 1, 2 and 3).

3.6.1. Capture

The collection receivers operate 24 hours a day so we will discard the notion of simultaneity factor Ks from which the collection generates an active power of around 2132.32 KW (see table III.18) for a cosine phi and tan phi respectively of 0.810 and 0.724 which we must try to reduce to 0.95 and 0.33 respectively. By relation III.11 and III.12 we will have:

$$Q_C = 2132{,}32 \times (0{,}724 - 0{,}33) = \mathbf{840{,}134\ Kvar}$$

3.6.2. Repression

The discharge also operates 24 hours a day, the active power generated will therefore be approximately 5178.95 KW for a cosine phi of 0.88 and 0.54 tangent phi.

$$Q_C = 5178{,}95 \times (0{,}54 - 0{,}33) = \mathbf{1.087{,}579\ Kvar}$$

3.6.3. Factory 1, 2 and 3

Plants 1, 2 and 3 respectively generate reactive power of 117.114 KW, 111.010 KW and 142.525 KW their cosine phi and tangent phi are shown in Table III.22.

Table 10Active power and cosine phi FACTORY 1, 2 and 3.

	P_a $total\ (KW)$	$\cos\varphi$	$\tan\varphi$
PLANT 1	117,114	0.869	0.569
FACTORY 2	111,010	0.892	0.507
FACTORY 3	142,525	0.875	0.553

$$Q_{C1} = 117{,}144 \times (0{,}569 - 0{,}33) = \mathbf{27{,}997\ Kvar}$$

$$Q_{C2} = 111{,}010 \times (0{,}507 - 0{,}33) = \mathbf{19{,}648\ Kvar}$$

$$Q_{C3} = 142{,}525 \times (0{,}553 - 0{,}33) = \mathbf{31{,}783\ Kvar}$$

3.7. Analysis after compensation

Let's assume that the REGIDESO N'DJILI industrial complex had compensated for the reactive power generated during the period from December 2022 to February 2023. As shown in Table 11. By installing capacitor banks, the penalties due to a bad cosine phi of 0 .95 will be canceled.

Table 11. Analysis of penalties (Source: REGIDESO)

Month of SNEL Billing (year)	Cos φ (<0.95)	Penalty in FC	Cos φ (=0.95)	Penalty in FC
December (2022)	0.89	13,217,492.66	0.95	0
January (2023)	0.93	6,621,875.81	0.95	0
February (2023)	0.93	3,479,787.59	0.95	0
June (2023)	0.92	7,848,612.33	0.95	0
July (2023)	0.92	9,416,980.44	0.95	0
Total		**40,584,748.83**		**0**

We note that REGIDE SO paid 40,584,748.83 FC or $19,751.5 USD (With 1$ USD = 2054.77 FC). This equates to approximately $6,432.56 USD in December 2022, $3,222.66 USD in January 2023, $1,693.50 USD in February 2023, $ 3,819.68 USD in June 2023, and $4,582.96 USD in July 2023. Consequently, REGIDESO SA spends on average $3,950.27 USD per month for these penalties.

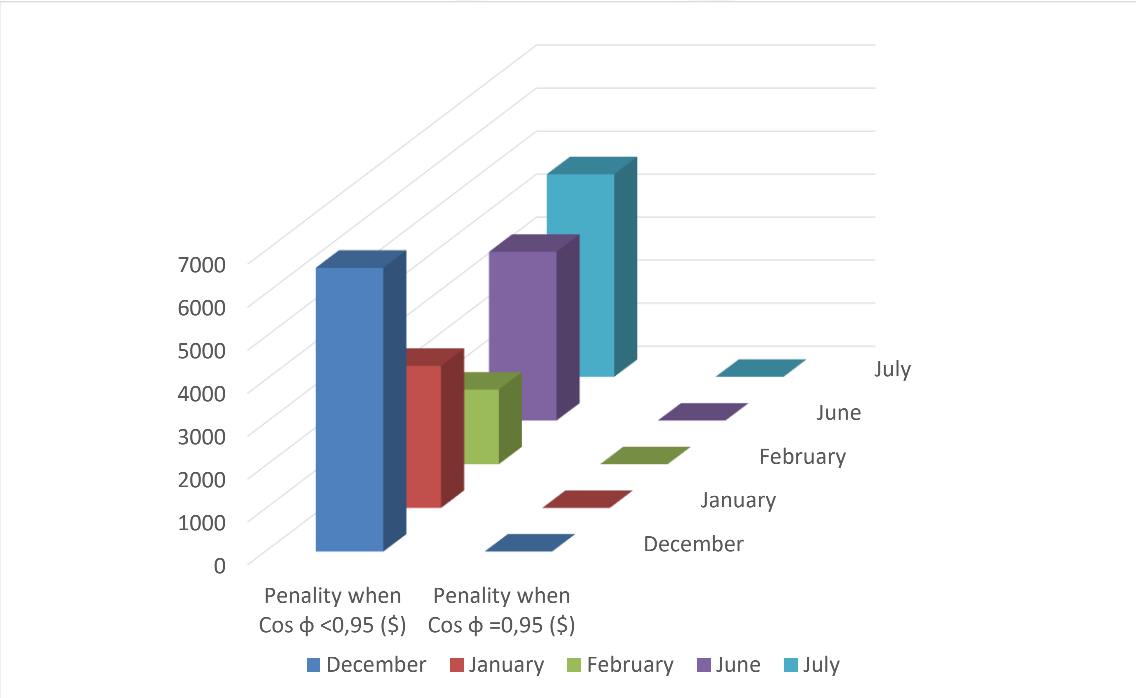


Figure 4. Comparative analysis of penalty when cos φ <0.95 and when cos φ = 0.95

Looking at the table, we see that the penalties decrease as the cosine phi approaches 0.95.

3.8. Investment estimate

Table IV.7 shows us the estimate of the purchasing cost of our sizing system:

Table IV. 12Cost of purchasing capacitor batteries (ITIS Commerce, 2023)

No.	Designation	Quantity	PU (€)	PT (€)
1	VARSET AUTO CAPACITOR BANK 900KVAR DISJ INPUT XXB	1	€29,222.29 (excl. tax)	€29,222.29 (excl. tax)
2	VARSET AUTO CAPACITOR BANK 1150KVAR DISJ INPUT XXB	1	€37,789.70 (excl. tax)	€37,789.70 (excl. tax)
3	VARSET FIXED CAPACITOR BANK 32KVAR DISJ HIGH INPUT	2	€1,406.64 (excl. tax)	€2,813.28 (excl. VAT)
4	VARSET FIXED CAPACITOR BANK 22KVAR DISJ HIGH INPUT	1	€1,338.11 (excl. tax)	€1,338.11 (excl. tax)

Total + 10% Unexpected = €71,163.38 + €7,116.338 = €78,279.718 or $84,499.04 at today's rate.

Installation costs depend from one installer to another but generally they correspond to 30% of the total cost of the project so for prevention, we can estimate the total investment cost at around $100,000.

By analyzing the electricity bills of the REGIDESO N'DJILI industrial complex, we assume that REGIDESO SARL will pay on average $3,950.27/month or $43,200/year in penalties for the N'DJILI complex since December 2022. Compare to the investment cost the investment payback period for the purchase and installation of the capacitor banks is 2 and a half years or approximately $129,600 to be saved in 3 years.

4. CONCLUSION

The results obtained during the analytical calculations are as follows: an active power of 7929.12 KW, a reactive power of 4692.09 KVAR and an apparent power of 9213.39 KVA. However, given the fact that the receivers are never all connected simultaneously in order to respect the subscription power, we have taken into account the simultaneity factor. Thus, the results were reduced to 4757.47 KW for active power, 2815.24 KVAR for reactive power and 5528.03 KVA for apparent power, with a power factor of 0.86. These results correspond to the subscription power of 6150 KW.

In the same vein, we carried out a power assessment using the CALCELECT software, which gave the following results: 4757.45 KW for active power, 2826.34 KVAR for reactive power and 5533 .67 KVA for apparent power, with a power factor of 0.865.

Our sizing calculations have demonstrated that to compensate for 4757.45 KW of active power with a power factor of 0.865, we will need capacitor banks. Since global compensation is not appropriate for our type of installation, we have proposed local compensations in all areas considered sensitive. Thus, we recommend capacitor banks for capture, discharge and plants 1, 2 and 3 respectively.

By reducing the power factor of each building to 0.95, SNEL SA will be able to cancel the penalties due to the incorrect power factor. We estimated the purchase, transportation and installation costs to be approximately $110,000. Knowing that REGIDESO SA pays on average $3,600 per month and $43,200 per year in penalties due to poor power factor, the payback period for the investment will be less than 3 years. Thus, REGIDESO SA will save $432,000 over the next 10 years, because the recommended capacitor banks have a lifespan of 10 to 12 years.

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