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Methods of attenuation for harmonics produced by variable speed drives used in a brewing company: Case of Bralima Kinshasa (RD Congo)

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ABSTRACT: This article encompasses a technical and mathematical description of the six-pulse drives used in industry and the verification of the percentage of current harmonics produced by each of them. An analysis of the total harmonic content produced by the six-pulse drives commonly used at Bralima RD Congo will be carried out, for this purpose the harmonic spectra given by the drive manufacturer are simulated in ETAP software to subsequently run a harmonics stream and assess compliance with technical service quality indices. In the event of non-compliance, the harmonic mitigation techniques will be plated and verified. The result includes analyzes and simulations based on real Bralima data and a technical guide for mitigating the harmonic currents produced by six-pulse drives is presented.

KEYWORDS: Six-pulse drives, load, harmonic content, power quality, harmonic content mitigation.

1 INTRODUCTION

One of the main concerns in industrial processes is the quality of energy, which is directly related to the payment on the electric bill, whether due to penalties for low power factor, current harmonic distortion, or unexpected electrical consumption as a result of the operation of nonlinear charges. These non-linear loads include among others: soft starters, variable speed drives, computers, UPS and other electronic devices such as lighting, welding material and uninterruptible power supplies [1]. Most non-linear loads used in different types of electronic systems can increase harmonic disturbances by injecting current harmonics directly into the distribution network. These loads generate harmonics that produce losses in the electrical distribution network.

Industries use variable speed drives of six, twelve and twenty four pulses to be able to control the speed of their rotating electrical machines. The six-pulse drive is the most economical for speed control applications and therefore is the most widely used equipment for production processes, either for starting motors or for speed regulation in processes. The power electronics present in these variable speed drives make them important non-linear loads present in power systems. At present there are severe international standards referring to electromagnetic compatibility, as well as local regulations to be complied with both by the companies providing electrical service and by the users themselves [2, 3].

In an effort to reduce costs in their equipment acquisition processes, industries select the six-pulse drive because it is the most economical, without taking into account its low performance and its significant contribution of harmonic content to the electrical network, this affects the users close to the industry's common point of attachment. The objective of this article is to carry out an analysis of the harmonic content produced by six-pulse drives in the industry and to determine an adequate method of mitigation.

2 FOUNDATIONS

Harmonic distortion in an electrical system is mainly caused by the connection of devices and non-linear loads in which the current is not proportional to the applied voltage. Figure 1 illustrates this concept, a sinusoidal voltage can be applied to a non-linear resistor, the voltage and current will vary according to the curve shown, that is, a small variation in voltage can cause large increases in current, in addition, It is observed that while the applied voltage is perfectly sinusoidal the resulting current is distorted due to the non-linear element.

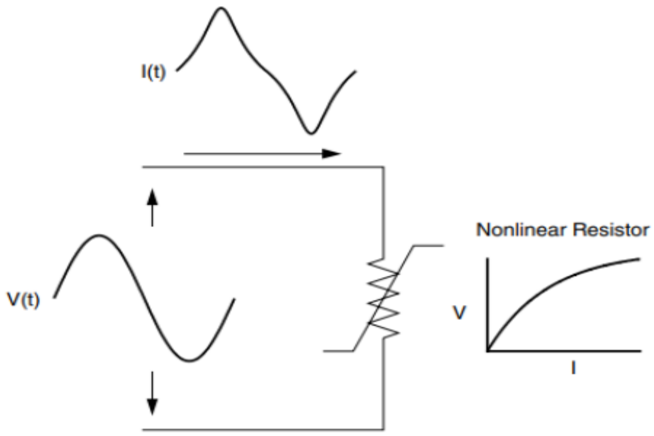

Fig. 1. Current distortion caused by non-linear elements [3]

2.1 STATIC POWER CONVERTERS

Static power converters are used in the industry to carry out the conversion process from alternating current to direct current through rectifiers, which are commonly six and twelve pulses. The order of the characteristic harmonic currents produced by a rectifier is given by the expression [4]:

$$h=k.\ p\pm1 \quad (1)$$

Where:

h= harmonic order

p= number of rectifier pulses (6 or 12)

k= integer number (1,2,3...)

And the magnitude of the harmonic currents is obtained by:

$$I_h=\frac{I_1}{h} \quad (2)$$

Where:

I_h = harmonic current of order h.

I_1 = magnitude of the fundamental current.

Figure 2 illustrates the spectrum of characteristic harmonics for the six-pulse rectifier, where it is observed that the fifth and seventh order harmonic currents are the largest.

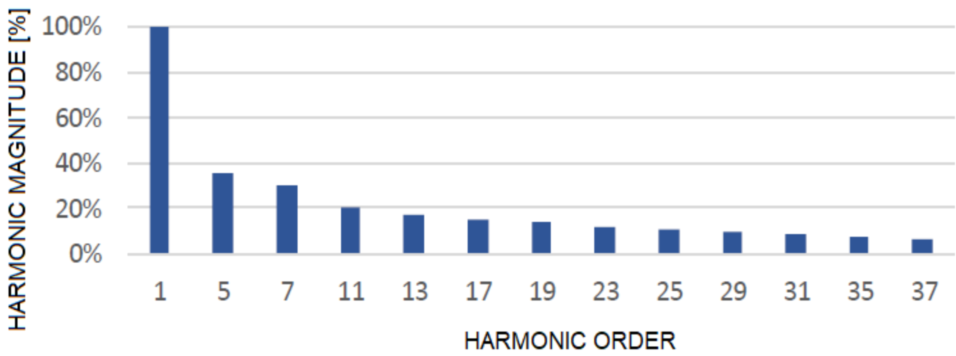

Fig. 2. ***Characteristic harmonic spectrum - six pulse rectifier***

2.2 IEE 519-1992 "Recommendations And Requirements For The Control Of Harmonics In Electrical Power Systems" [5, 6]

This guide will be used in the design of power systems with nonlinear loads. The limits established in this document are for steady-state operation and it is advisable to assume "the worst conditions". Transient conditions may be encountered that exceed these limits. In any case, the limit values indicated in this document are recommendations, there is a certain ideology that should not be taken into account in certain cases.

This standard must be applied at the connection points between the distribution system and the users. The limits of this standard are intended for application at the point of common coupling (PCC) between the distribution system and the user, where the PCC is generally the closest point to the distribution system where it offers its service to the most users.

2.2.1 Recommended Harmonic Voltage Limits

At the PCC, the distribution system or users must limit the line-to-neutral voltage harmonics in such a way that they comply with Table 1:

Table 1. ***Value of currents per harmonic order.***

Individual voltage at the PCC	Individual Harmonic (%)	THD (%)
V ≤ 1.0 kV	5.0	8.0
1 kV < V <69 kV	3.0	5.0
69 kV <V < 161 kV	1.5	2.5
161 kV < V	1.0	1.5

2.2.2 Recommended Current Distortion Limits For Systems Rated 120 V To 69 Kv

The limits in this standard apply to users connected to systems where the nominal voltage at the PCC is from 120 V to 69 kV. At the PCC, users must limit their harmonic currents according to Table 2.

Table 2. ***Current distortion limits for systems rated 120 V to 69 kV.***

Maximum harmonic current distortion in percent of IL *						
Individual harmonic order (odd harmonics) **						
Isc/IL	3<=h <11	11<=h<17	17<=h<23	23<=h<35	35<=h<50	THD [%]
<20***	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

3 METHODOLOGY

3.1 PRACTICAL GUIDE FOR THE MITIGATION OF HARMONICS IN THE INDUSTRY

The description of the processes carried out by an industry is necessary to have an idea of the electrical elements that interact within each of the processes and the electrical effects that occur when executing them.

3.1.1 DESCRIPTION AND GEOGRAPHICAL LOCATION OF THE INDUSTRY

The geographic location of the industry is useful for modeling and simulation of the industry, based on the location, the Thevenin equivalent is requested at the point of connection to the energy distribution company that supplies energy to the sector where the facilities operate.

3.1.2 MEDIUM VOLTAGE DATA

This data is provided by the distribution company that provides energy to the region where the industry operates. The main connection starts from the distribution transformer closest to the industry and ends at the high voltage terminals of the transformer that will supply the industry's demand.

3.1.3 LOW VOLTAGE DATA

The secondary connection begins from the low voltage terminals of the transformer that will supply the demand of the industry in question, and ends at the entrance of the equipment used for the energization or de-energization of electrical equipment in the industry (Switchgear), equipment used for motor control (MCC).

3.1.4 VARIABLE SPEED DRIVES

Variable speed drives are systems that are located between the electrical power supply and the electric motors. They are used to regulate the speed of rotation of alternating current (AC) motors. The plate data necessary for the simulation of an industry that has variable speed drives are:

- Rated voltage [V]
- Rated current [A]
- Current harmonic spectrum [%]

3.2 MODELING AND SIMULATION

To carry out the simulation of an industry, it is necessary to use software which must be friendly when entering data, performing power flows, calculating short circuits, harmonic flows and dynamic simulations in each of the scenarios required by the user.

The ETAP 19.0.1 simulation software is a friendly software, it has the necessary modules to carry out: harmonic flows, short-circuit analysis, power flows, electric arc analysis, etc.

3.2.1 INDUSTRY DESIGN

In order to make an ideal and representative diagram of an industry in ETAP 19.0.1, it is necessary to have as a reference a single-line diagram of the industry in detail, in which the plate data collected previously has been specified: thevenin equivalent, main connection, transformer, secondary connection, switchgears, MCC's, variable speed drives and high power loads.

3.2.2 DATA ENTRY IN THE SOFTWARE ETAP

With the single-line diagram of the industry modeled in ETAP, the collected data is entered, one of the most important data is the value of the Thevenin equivalent.

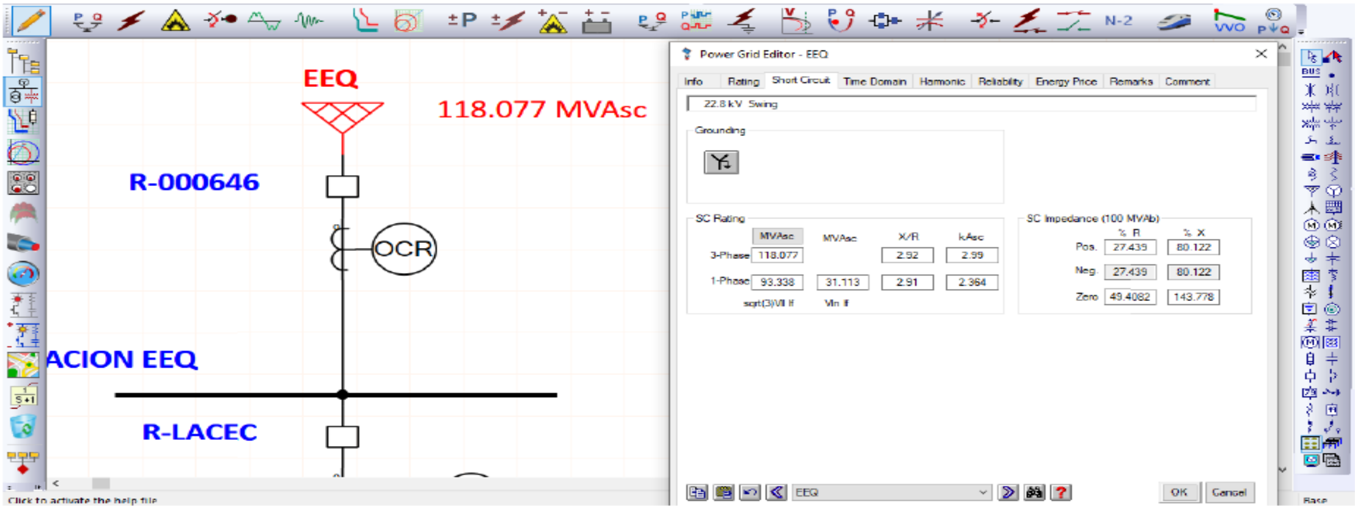

Fig. 3. Thevenin equivalent data entry

Figure 2.4 details the data requested by the equivalent module of thevenin (power grid editor) in ETAP, these are:

- Information (info): this tab is used to include all the information about the network to which it is connected, identification, type of network, etc.
- Classification (rating): this tab is used to include the nominal value of the voltage that thevenin equivalent will deliver to the industrial user.
- Short circuit: this tab is used to include the information provided by the power distribution company in order to model the electrical network as a source for studies of short circuits, harmonic flows, power flows, motor starting, transient stability, coordination of protections, etc.

The tabs detailed above are the most important for modeling the network to be studied.

3.3 Design Of The Harmonic Filter For The Mitigation Of Current Harmonics

The design of a harmonic filter requires information about the power system and the environment in which the harmonic filter will be installed. This information includes system characteristics such as the nominal line-to-line voltage of the system, the typical BIL of the equipment for the system voltage level, and the fundamental frequency. Environmental data, such as ambient temperature, wind load, etc., must be available. The owner must make decisions, such as the location of the equipment (interior or exterior) and operating restrictions, before the design begins, since these decisions will affect certain aspects of the design. A clear understanding of the equipment's current duty cycle and switching repetition rates is also important for design.

On-site harmonic measurements are the most accurate means of obtaining harmonic information if loads are already installed. Otherwise, the equipment manufacturer must provide the harmonic characteristics.

3.3.1 Steps To Design Harmonic Filter

Step 1: Determination Of Reactive Power For The Harmonic Filter

In addition to harmonic filtering, the filtering equipment will provide the system with capacitive reactive power that will improve power factor and help maintain voltage under high demand conditions.

Power flow schedules are often used to determine capacitive reactive power requirements. Factors that should be considered when conducting these studies are:

- Number of steps of the harmonic filter capacitor to be switched.
- System voltage variation range.
- Load variation range.
- Power system configurations: normal and contingency, existing and planned.

STEP 2: SELECTING THE HARMONIC FILTER TO TUNE

Based on the generation of harmonics, an initial estimate of the tuning of the harmonic filter will be made. Tuning is done to reduce harmonic voltage and current distortion to meet this goal, the harmonic filter will normally be tuned to the lowest frequency of the most significant harmonics.

STEP 3: OPTIMIZING THE FILTER DESIGN

Harmonic studies will make it possible to determine the quantity, tuning and location of harmonic filters based on compliance with established or regulated harmonic content limits. Factors to consider when conducting these studies are summarized below:

a) Number of harmonic filter steps to be switched
b) Interruption of a harmonic filter, if more than one harmonic filter is used
c) System voltage variation range
d) Range of load variation
e) Normal and contingency power system configurations
f) Detuning of the harmonic filter due to changes in the system frequency, component manufacturing tolerance range, capacitance variation with severe temperatures and harmonic filter capacitor unit outages
g) Characteristic and non-characteristic harmonics
h) System background harmonics

If the distortion levels are still too high, it may be because the addition of a harmonic filter has caused a new parallel resonance with the system near one of the lower frequency harmonics. In this case, it may sometimes be appropriate to retune the harmonic filter to the lower harmonic frequency. If not, multiple tuned harmonic filters may be required.

STEP 4: CLASSIFICATION OF THE COMPONENTS

Once the performance of the harmonic filter is optimized, the component ratings are determined. Sometimes the process is iterative, requiring adjustments to the harmonic filter design if component standards cannot be met.

4 RESULTS

4.1 APPLICATION OF THE DESIGN GUIDE FOR THE MITIGATION OF HARMONIC CONTENT IN THE BRALIMA INDUSTRY

4.1.1 MAIN DATA OF THE BRALIMA INDUSTRY

The information for the determination of the Thévenin equivalent at the connection point of the BRALIMA industry is provided in Table 3 where the values of the connection point are detailed.

Table 3. Thévenin equivalent at the connection point Bralima Industry

Substation/ Primary	Voltage Level (kV)	Type of fault	Ikss (kA)	Skss (MVA)	Ip (kA)	R1 (ohm)	X1 (Ohm)	R0 (ohm)	X0 (ohm)
58A	22.8	Triphasic	2.96	68.12	7.28	15.88	46.51	N/A	N/A
		Single Phase	2.34	31.15	5.74	15.88	46.51	28.78	83.33

4.1.2 Main Connection

The BRALIMA industry is interconnected with the electrical system of the SNEL Company at the medium voltage level (20 kV) in the 58 A primary from the HC-2000 pole with an OID-214081 knife-type disconnector in series with a recloser; From here, a three-phase feeder of caliber ASCR-4/0AWG for the phase and ACSR-1/0 for the neutral starts, with an approximate length of 398 m up to the PC12-500 pole. The OID-214082 disconnector is located at this point and starts a derivation with a distance of 80 m towards the T-175648 150kVA-20 kV/220V transformer.

4.1.3 Speed Variators

The variable speed drives installed in the industry are of different powers since they are associated with different motors in each of the work areas. Table 4 presents the most important data of the industry's variable speed drives.

Table 4. Thévenin equivalent at the connection point Bralima Industry.

FC speed variator	Nominal Voltage [V]	Nominal Current (ND) [A]	Nominal Current (HD) [A]
FC110003T4OFAYZ	380-400	13.5	11
FC110038T4OFAYZ	380-400	88	71
FC110088T4OFAYZ	380-400	211	180
FC110370T4OYZ	380-400	370	312
FC110477T4OYZ	380-400	398	286

The equipment used in the Bralima industry in the different production areas generate current harmonics of order 5, 7, 11, 13, 17, 19, etc.; Figure 4 indicates the characteristic harmonic spectrum of these equipment referenced to the standard.

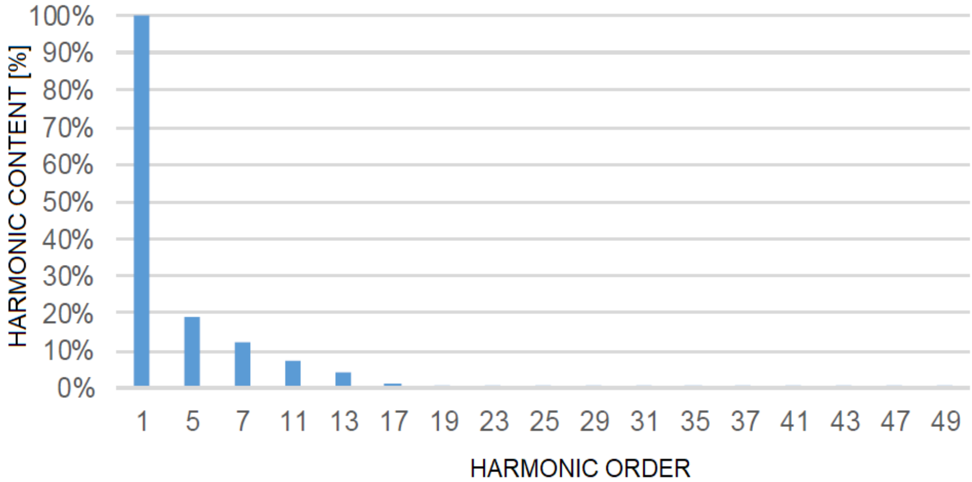

Fig. 4. Harmonic spectrum for six-pulse FC drives

Based on measurements obtained from a network analyzer installed in the FC110307T4OYZ drive for a period of 6 minutes at 20-second intervals, the data of the generated harmonic content was obtained, which is presented in Figure 5.

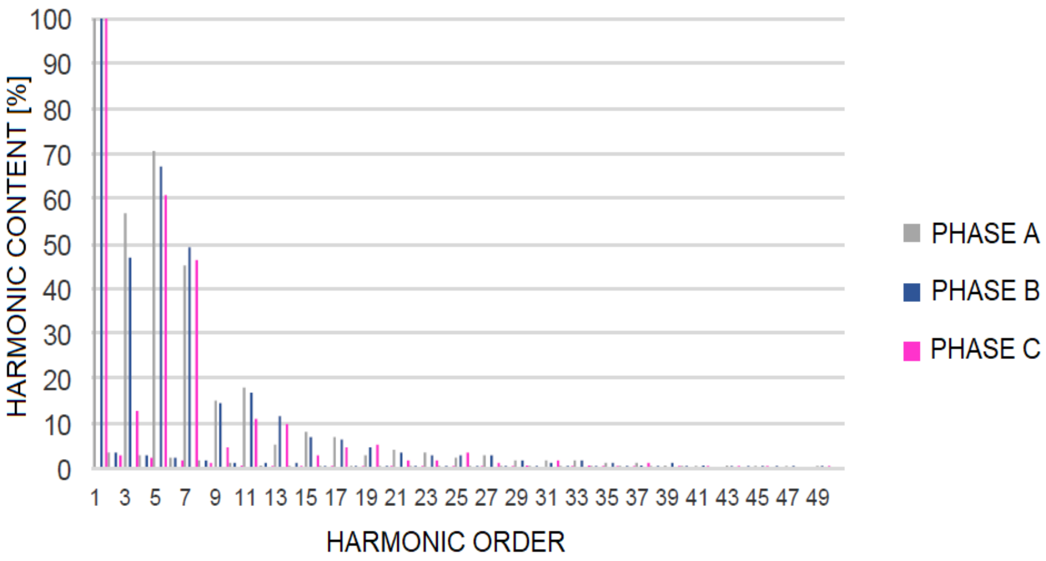

Fig. 5. FC110307T4OYZ current harmonic spectrum

4.2 Harmonic Filter Design

The harmonic content generated by the six-pulse drives installed in the industry is very high and this generates a large consumption of unnecessary electrical energy and distortion in the voltage and current waves throughout the industry. An alternative to reduce unnecessary consumption and improve the quality of the waves is the installation of passives filters.

In the case of the Bralima industry, there are data on the harmonic flow obtained from the simulation, on this basis the design of the harmonic filter that mitigates the harmonic content of the industry is carried out.

Therefore, we proceed to model the active filter in the Etap software and verify if it mitigates the disturbances that are present in the industry.

At the time of incorporating the filter in the simulation, the values of the ICC/IL and TDD ratio change, Table 5 has the values obtained in the simulation without the incorporation and with the incorporation of the harmonic filter.

Table 5. Individual current THD and voltage THD on the industry PCC

COMPARISON	UNFILTERED	WITH FILTER
ICC/IL	37.450	42.090
TDD [%]	23.808	12.976

5 Analysis

The simulations carried out in this article consider a detailed modeling that allows creating operating scenarios that adequately approximate the real operating conditions of the industry under analysis, in this way it is possible to obtain more real values of power flows and harmonic flows in the different operating scenarios. To carry out a power quality analysis in an industry that has non-linear loads, it is necessary to have extensive knowledge about the electronic and electrical equipment that generate disturbances and what are the possible solutions that can be applied to reduce the harmonic content generated.

6 Conclusion

In this article, for the evaluation of the current harmonic content produced by the industry, the TDD indicator was used, with which a general evaluation of all the harmonic content was made, thus allowing to avoid making an individual comparison of the harmonic content. The filters, calculated to reduce the harmonic content, are of simple characteristics and have a resonant impedance at low frequency. The harmonic spectrum of variable speed drives typically used in the industry, obtained through measurements, does not resemble the one provided by the manufacturer. It is important to be clear about the concept of PCC (common coupling point) since there is a lot of confusion between the place of installation of the filter and the place of measurement of the harmonic content. In the first case, the load where the highest content is being generated is sought. harmonic, to install the filter near that place, and in the second case, it is the place or site where the distribution company measures the harmonic content, generally in medium or high voltage.

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