EFFECTS ARISING FROM DISTURBANCES IN THE ELECTRIC POWER SUPPLY, IN PRODUCTION PROCESSES IN THE CERAMIC SECTOR. SEARCH FOR SOLUTIONS

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ABSTRACT

The study sets out the experiences and results obtained in the project being carried out by IBERDROLA on disturbances, with regard to enterprises in the ceramic sector, thus contributing to optimization of the manufacturing processes.

Several disturbances found in the power mains are described, and disrupting elements as well as sensitive elements are identified in the ceramic industry.

On establishing the possible impact on the different production process stages, solutions are proposed to mitigate the effects of micro-outages or dips in voltage, in order to reduce the negative effects on quality and productivity in the industry. The solution regarding the solenoid-operated valves that control gas flow and its feasibility, were specifically studied.

1. INTRODUCTION

Electric power is generally an essential element in production processes. Improving the quality of electric energy is a challenge for the electric power supplying companies, as it is currently no longer enough to "have electric power", but it is necessary to "have quality electric power". The increase in the number of facilities that are sensitive to disturbances and the proliferation of contaminating receivers require that electric power suppliers and consumers become increasingly willing to cooperate in maintaining a system of sufficient quality so that undesired anomalies will, as far as possible, not arise.

Aware of this, IBERDROLA has been developing a project in collaboration with the Department of Electrical Engineering of the Universidad Politécnica de Valencia and UITESA, entitled: "Study of Micro-outages in the Spanish Electric Mains, and methods for minimizing their impact".

The project is being developed for certain kinds of industrial processes, and it is hoped it will have wide application in the ceramic sector.

2. PRIOR CONSIDERATIONS

To start with, in order to describe the environment in which the project has been carried out, some objectives and stages that were fixed to perform the study are briefly discussed.

An overview is also given of the kinds of disturbances that exist, their possible causes and initial results, which will help to illustrate the real magnitude of the problem.

2.1. OBJECTIVES

The general objective is to attempt to contribute to the development of methods that will allow the economic, technological and social harm arising from disruptions in the electric power supply to be reduced, both at the supplying company as well as at its customers'.

With this aim, the following partial objectives were set:

Determining the kinds of disturbances

Causes and classification of the disturbances

Effects at the facilities of the ceramic customers and at the facilities of the electric power supplying company.

Technical solutions to reduce their arising, limiting propagation and decreasing their effects.

Economic assessment of solutions.

2.2. STUDY PHASES

The study comprises the following phases:

Gathering information.

Determining study zones: 10 medium voltage lines were chosen in the province of Castellón, predominantly in the ceramic sector.

Installation of equipment for recording sophisticated disturbances, at different points in the electric power mains and at the customers' according to the established sampling plan.

Study of the impact on the affected production processes and associated regulations.

Determination of the characteristics, origin, cause, and impact of the disturbances.

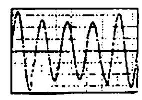
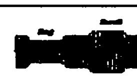
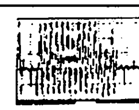
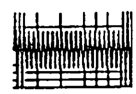
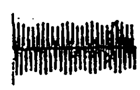
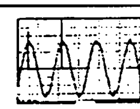
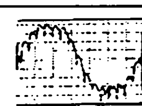
Technical-economic study of the possible solutions.

Practical verification of the possible solutions.

2.3. KINDS OF DISTURBANCES

Considering a disturbance to be any phenomenon that gives rise to deviation in the values of the characteristic power parameters: frequency, amplitude, waveform and triphase symmetry, in terms of the kinds of disturbances conducted by electric power mains. The anomalies detected in the mains can be broken down as shown in Grid 1.

Grid 1. *Definitons of disturbances*

Designation of disturbance	Other designations		Description		Remarks	Stardars from
	USA	Europe UIE	Voltage	Duration		
Hueco	Sag	Dip	0,1 < ΔU < 0,9 0,1 < ΔU < 0,99	10ms < ΔT < 0,5s 10ms < ΔT < 2m 10ms < ΔT < 1m	NPL BMI UIE	
Sobretensión breve	Surge swell		ΔU > 1,1	10ms < ΔT	BMI	
Interrupción	Interruption	Short interruption	ΔU > 0,9 ΔU > 0,99	10ms < ΔT < 2m 10ms < ΔT < 1m	BMI UIE	
Corte		Outage	ΔU > 0,9 ΔU > 0,99	2m < ΔT 1m < ΔT	BMI UIE	
Subtensión	Under-voltage		(typical value) 0 < ΔU < 0,2	2m < ΔT 1m < ΔT	BMI UIE	
Sobretensión	Overvoltage		(typical value) 1 < ΔU < 1,2	2m < ΔT 1m < ΔT	BMI UIE	
Flicker		Flicker	(typical value) 0,9 < ΔU < 1,1			
Impulso	Impulse	Transtert overvoltage	Very steep slope			
Deformación de onda	Wavefrom disturbance		Sinusoid and/or harmonic distortion (slope)			

The present study specifically focuses on voltage waveform disturbances lasting less than a minute.

2.4. ORIGIN AND CAUSES OF THE DISTURBANCES

Two groups are distinguished in order to identify the phenomena giving rise to disturbances:

* **arising in the mains:**

They include all those occurrences that take place in the mains and affect the quality of the power supply. Some of these phenomena are:

Tripping automatically reclosing power line head switches,

Inopportune tripping of safety measures in general, owing to weather conditions, material defects, etc.,

Failures in lines and switchgear,

Manoeuvres in condenser batteries,

Planned manoeuvres,

Connecting and disconnecting great loads, etc.

It should be highlighted that a certain number of voltage alterations are inevitable in the mains and in turn constitute a measure of the good functioning of the system.

* **arising at the customer's facility:**

An important number of disturbances are caused by receivers and actions at the industrial facilities themselves, which can impact elements at the same facility or even be transmitted to the mains. These involve electronic systems with non-linear voltage-intensity characteristics, rotating machines with strong starting power requirements, failures at the receiving installation itself, etc.

On the other hand, the frequency with which these disruptive phenomena arise leads to a new classification:

* **random disturbances:**

Unforeseeable phenomena are involved, of an accidental nature. These can arise for instance because of:

weather conditions,

connecting or disconnecting loads,

manoeuvres in condenser batteries,

short circuits or failures in general, both in the user's facilities and in the mains.

* **permanent or stationary disturbances:**

This group includes those disruptions whose appearance is foreseeable and are generally caused by receivers installed at the user's, of a permanent or temporary character, so that disturbances arise during certain periods of time, as may be the case of presses operating with a frequency of 15 to 20 strokes per minute.

2.5. INITIAL RESULTS OF THE SAMPLING PLAN

The following data can be described as the initial results of the sampling plan carried out on the lines in the study area:

Opening the line head switch entails a voltage dip in the lines connected to the same bars at the transformer substation.

Generally speaking, two kinds of dip are observed, one with an earth fault and others that are due to diphase or triphase short circuits, or to disturbances that come from high tension and have differing repercussions according to whether the customer has a cogenerating facility or not.

A correlation is observed between the number of dips detected in a set of associated lines (linked to the same bar), and the number of customer transformation centres they supply, kind of activity developed, length and branchings of the lines, weather conditions in the area and even environment conditions (health, moisture, etc.)

It can be stated, indicatively, that 90% of the dips or brief interruptions recorded last less than 1 s.

3. REPERCUSSIONS IN THE CERAMIC SECTOR

The technological evolution in the ceramic sector has led to widespread implementation of fast firing, which requires more sophisticated kiln control, and in turn makes it necessary to have a better quality electric power supply.

This study intends to assess the repercussions that the kind of disturbances set out above have on the production process, and their influence on product quality.

Having identified the elements of the industrial facility that are most sensitive to disturbances, the most representative disruptions are detailed, whose greater or lesser importance derives from the degree in which they affect safety, quality, and productivity in industry.

3.1. INFORMATION SOURCES

To perform a diagnostic of the current situation and the degree to which the ceramic sector is affected, data were compiled from the following sources:

Mail survey involving a great many companies.

Visits to 59 firms from the ceramic sector, including manufacturers of ceramic products, suppliers and installers of equipment for the ceramic production process.

Recordings obtained from installed disturbance recording equipment.

Opinions of associations and institutions related with the sector:

ASCER: Asociación Española de fabricantes de azulejos, pavimentos y baldosas cerámicos.

AICE: Asociación de Investigación de las Industrias Cerámicas.

ENAGAS: certifier and regulator of burners, well-acquainted with kiln workings and specifically with gas-related safety issues.

SERVICIO TERRITORIAL DE INDUSTRIA EN CASTELLON, well-acquainted with the sector's problems.

3.2. IDENTIFICATION OF THE DISTURBING ELEMENTS

The following details the elements that may disturb the electric power supply in the ceramic sector:

Glaze mills and slip drums, where irregularities occur in operation, with very high starting points.

Press motors, working with batch loads.

Reloading that does not take place in stages.

Customer transformation centres, at which an important lack of attention is sometimes detected, exhibiting dust in the enclosure and facilities, signs of moisture on the ceiling and especially in the tower for overhead incoming supply.

Equipment for improving the power factor, where condenser batteries have been detected which do not function in stages, that is, at 100% or 0%

Earth settings, a general lack of awareness being observed.

Load imbalances, in the internal lines of supply of the customer himself.

3.3. IDENTIFICATION OF SENSITIVE ELEMENTS

The differing impact of electric disturbances on the workings of an industrial facility, specifically in the ceramic industry, allows two groups to be distinguished:

CONTROL SYSTEMS AND SAFEGUARDS:

These have priority in studying the sensitivity of the facility. They are characterized by a reduced energy consumption and possess negligible inertia. The ceramic sector distinguishes as especially important:

solenoid-operated valves, which control the gas flow to the burners in kilns and in spray dryers. In view of their important repercussion on the process, the problems they involve will be addressed in a subsequent separate section.

Microprocessors and programmable automatons utilized in process control, proportioning clays, firing, feeding material to the presses, classifying the finished product, etc. Their correct functioning generally requires that the voltage should remain within $\pm 10\%$ of its nominal value. However, voltage disturbances of a greater amplitude, though of short duration (of the order of tens of ms) are sometimes tolerated. Beyond these margins, information losses and errors in executing calculations can arise.

Other elements having less repercussion may also be affected:

contact-closers and -breakers, mainly used in connecting and disconnecting motors. These are immediately reactivated and do not entail any special problems for the production process.

non-linear consumption loads, like power rectifiers, are designed to support appreciable variations in their feed voltage. However, the low power absorbed by the ones used in the sector make it quite an insignificant matter.

safety systems

MACHINES:

It could be said that in particular in the ceramic sector, 90% of the load is formed by **induction motors**. They consume a high amount of energy and their inertia is considerable. They are, however, less sensitive to power dips. The most important ones drive the large fans, glaze pumps, clay crushers, compressors, etc.

3.4. INFLUENCE ON THE PRODUCTION PROCESS

As stated above, waveform disturbances affect different elements whose functioning depends on electric energy: motors, control and monitoring circuits, exhibiting different sensitivities in the face of possible disturbances.

The following activities in the production process in the ceramic industry, are singularly affected.

firing

This is the most sensitive activity. The kiln stops working with several possible effects:

closing of the automatic solenoid-operated valve regulating gas flow to the burners in the kiln.

shutdown of the roller-driving system in the kiln.

stoppage of the combustion air fan and flue-gas extractors.

loss of control of the firing process.

spray drying

The spray dryer's basic element is a burner that provides the necessary calories for its operation. The fundamental effects of a power dip are summed up in the following:

Closing of the automatic solenoid-operated valve that regulates gas flow to the burner, entailing the possibility of sludge formation at the bottom of the spray dryer.

Breaking of the contacts in the pump motors, with the possible blocking of the slip sprayers owing to the thermal inertia inside the spray dryer.

pressing

A power failure causes the presses to stop, which can give rise to deformations in the dies as a result of press weight. As they are regulated by control systems that are sensitive to disturbances, anomalies such as a loss of synchronization can arise, possibly entailing mechanical damage.

outgoing lines of finished product

The processes involving transport and sorting of the finished product are regulated by programmable automatons and microprocessors, which can undergo operational changes, such as:

Interruptions in the transport process,

Information loss.

3.5. EFFECTS OF MICRO-OUTAGES IN THE CERAMIC INDUSTRY

In assessing the effects of micro-outages, it is useful to distinguish two essential parts that are closely related and have clear economic repercussions,

Quality of the finished product

Drop in productivity

3.5.1. Quality of the finished of product

The disruptions mentioned affect product quality to a certain extent. Thus, for example, any change in slurry composition owing to failure of a programme proportioning clays can affect the mechanical properties of the pieces. Pressing defects can also give rise to unsuitable compaction. However, firing is the most critical activity in the process, as it is in this stage that the piece acquires the targeted properties and qualities for the finished product.

Firing different materials requires specific temperature and atmosphere conditions inside the kiln. Shutdown of the kiln involves a rapid drop in temperature inside the kiln, owing on the one hand to the low thermal inertia that characterizes current single-layer kilns, and to loss of ventilation, also modifying heat distribution throughout the kiln. This can cause temperature to fall to 100 °C, depending on the time the interruption lasts. This all noticeably alters the programmed firing schedule. It gives rise to an uncontrolled firing process that entails defects in the material in the course of firing, which leads to product rejects or, in the best of cases, markedly impaired quality.

This loss of quality is caused by,

unwanted changes in the structure of clays and glazes. Internal fissures and cracks are involved, that are not always visible, making the product brittle.

loss of planarity or variation in dimensions of the pieces, with wedging and differing sizes.

appearance of black coring owing to unfinished oxidation.

variations in compaction.

variations in vitrification of the product.

changes in colour or appreciable differences in shades.

changes in mechanical properties, etc.

3.5.2. Drop in productivity

An accidental stoppage of the process involves a drop in productivity for three reasons:

material and finished product

Material losses arise mainly inside the kiln, with finished product loss, owing to the impaired quality mentioned above.

downtime

However short the interruption in the power supply may be, restarting the process complying with the sequence laid down in the regulations for relighting, requires a certain time that will hardly be less than 5 minutes. This also depends on kiln characteristics and the specific facilities involved. An additional time must also be taken into account in order to attain a normal work situation again.

deterioration of equipment

Damage can be caused to equipment such as dies, rollers, spray-dryer nozzles, whose diagnostic is not always immediate, giving rise to a finished product with deformations that will be detected by end quality control, with its consequent effect on productivity.

4. PROPOSED SOLUTIONS

Taking decisions to minimize the effects of the disturbances should occur in collaboration with the Electricity Company, Servicio Territorial de Industria, equipment manufacturers, and users, establishing courses of action concerning the mains and the user's facilities.

Focusing on the customer's facilities, although there are no generally valid solutions, some preventive measures can be highlighted, which assure the insensitivity of the facilities to disturbances. In general lines, the following are proposed:

4.1. ACTIONS CONCERNING THE ELECTRICAL FACILITIES

Removing the person responsible for the existing deficiencies at the transformation centres.

Preventive maintenance at the transformation centres.

Analysis of possible load imbalances.

Checking of the state of the earths.

Individualized supply for sensitive loads.

Suitable policy in coordination and calibration of safeguards.

4.2. ACTIONS CONCERNING SPECIFIC EQUIPMENT

Filter in rectifiers

Solutions with an energy reserve of the SAI kind, or electrogen groups, currently adopted for control systems and roller movements respectively.

Decreasing the sensitivity of contact-closers and -breakers, acting on opening times.

PROPOSAL FOR A DELAY IN THE ACTION OF THE SOLENOID-OPERATED VALVE REGULATING GAS FLOW. CRITICAL SOLUTION THAT WILL BE ANALYZED BELOW.

5. THE PROBLEM OF THE AUTOMATIC SOLENOID-OPERATED VALVE REGULATING GAS FLOW

The solenoid valve regulating gas flow is an especially critical item in the production process of the ceramic industry, as kiln and spray dryer functioning or shutdown depend on it.

At present, the solenoid gas valve closes relatively frequently, causing considerable damage, which is not proportional to the kind of disturbance causing it.

The excessive sensitivity on the one hand, and the heterogeneity in the response detected in different kilns when there are voltages dips and micro-outages, have led to a search for solutions that could provide a criterion for common action, in coherence with the safety it is intended to assure.

The criteria for actuating the solenoid-operated valve are described in the relevant regulations. In this sense, the adoption of any solution must involve an analysis of these regulations.

5.1. REVIEW OF THE REGULATIONS

Gas kiln facilities are governed by the Regulation for facilities that use gas as fuel, approved by Royal Decree 494/1988 of 20 May and its Complementary Technical Instruction (ITC) of Order 29375 of 15 December 1988, ITC MIE-AG20. In this ITC, reference is made to Standard UNE 60-740-85 on burners, as being the recommended standard, and in some terms (safety times), as being the required regulation to be applied.

The requirements that the regulations impose in respect of the action of the solenoid-operated valve that regulates gas flow, can be summed up as follows:

While there is gas flow to the burners the safety devices must remain ready on standby. Control and monitoring of the kiln may at no time fail.

If the safety devices act, the solenoid valve regulating gas flow will close, causing shutdown due to flame failure, or for safety reasons, according to the safety device causing it, with safety times laid down in the UNE standard mentioned above.

In the case of power failures, the gas flow must be automatically shut off. This statement involves a certain lack of precision, as no duration or magnitude of the failures is specified, nor are safety times specified when this occurs.

5.2. APPLICABLE SOLUTION

Given its random character and the impossibility of completely eliminating voltage dips and micro-outages lasting less than 1-2 s, the following solution is proposed:

Study of a suitable delay in the manoeuvre closing the solenoid valve, so that is sufficient to allow these moments to be spanned, permitting the gas supply to continue in this time interval. If the power failure lasts beyond this interval of time, closing of the valve must follow immediately.

It is convenient to highlight that safety and control devices should be kept ready on standby, so that it will be necessary to have some method supplying or maintaining power for monitoring and control (around 2.5 kW) during this time interval.

Although this solution does not entail eliminating all the effects, it does solve the problem to a great extent.

5.3. STUDY OF THE FEASIBILITY OF THE PROPOSED SOLUTION

As observed, the action of the solenoid-operated valve controlling gas flow is conditioned by the safety measures with which the kiln is equipped:

Combustion air pressure

Flue-gas extraction pressure

Gas pressure

Flame control

It can intuitively be assured that a failure lasting a short time (less than 2 s), does not involve any immediate combustion loss, since the magnitudes determining this do not undergo instant changes.

To endorse the proposed solution, a theoretical study has been performed, which illustrates the influence of power failures on the safety measuring magnitudes.

Maintaining gas pressure is independent of power failure, while the values of combustion air pressure and flue-gas extraction will depend on how the fans are affected, which provide these magnitudes. In this sense, the theoretical study focuses on fan behaviour in the face of these disturbances.

5.3.1. The fan when faced with power loss

The working point of a fan fitted to a facility is defined by the pressure-flow rate pair of values (p-Q), which are found for a fan at a certain speed. The change in revolutions of the fan will therefore modify initial pressure and flow rate values.

The safety conditions corresponding to the formation of the mix and extraction of flue gases are based on pressure measurements at the fans.

By the laws of fan similarity, the speed changes can be related to pressure changes according to the equation:

$$p_2 = p_1(n_2 / n_1)^2$$

Furthermore, through the dynamic study of the motor-fan unit, the time can be determined that this unit takes in going from one running speed n_1 to a new work point characterized by n_2.

$$t = (1/n_2 - 1/n_1)\ I/K$$

Thus, the times for reaching safety conditions are obtained in function of the moment of inertia of the motor-fan unit (I), fan power constant (K) and starting running speed (n_1).

Figures 1 and 2 show the influence of the value of these variables in fan downtime. The most critical form of work for a fan is observed to be high speeds, that is, corresponding to large kilns that require greater flow rates.

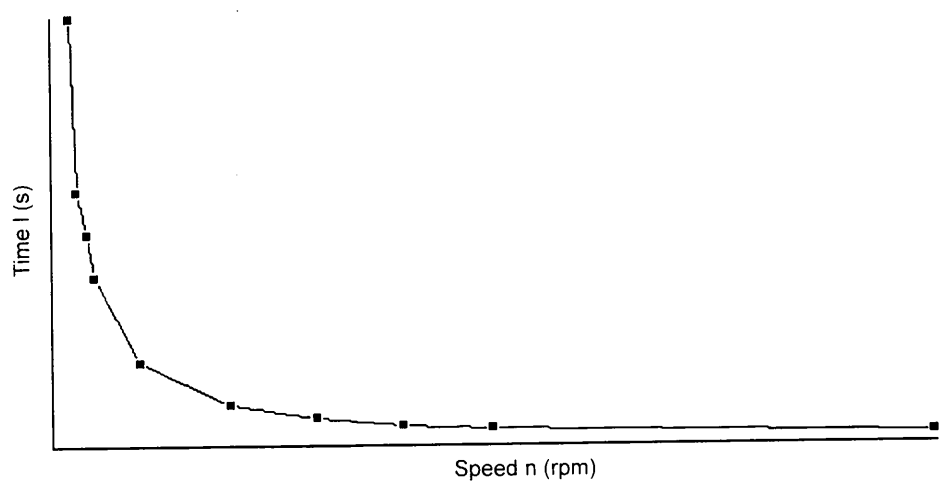


Figure 1. *Time to reach safety conditions*

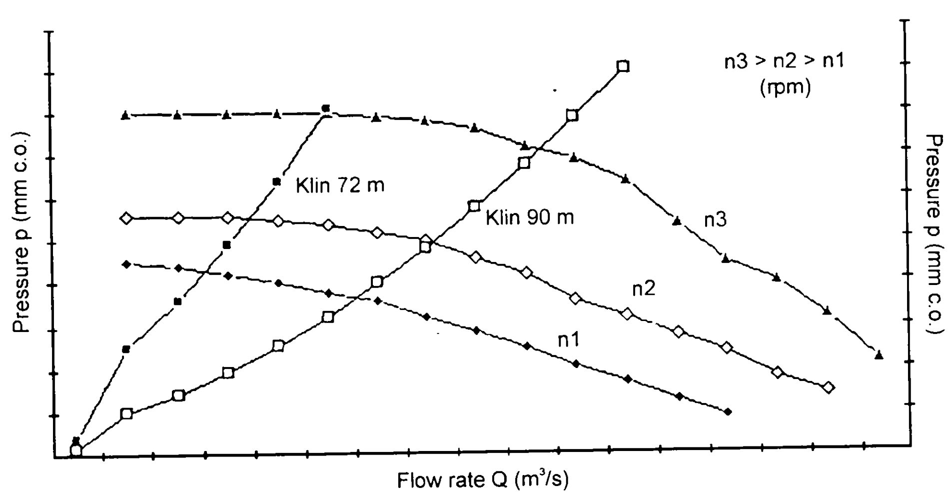


Figure 2. *Fan connected to different kilns*

5.3.2. Some results

The great proportion that ceramic floor and wall tile manufacture represents in the ceramic sector, allows the single-layer kiln to be considered as a representative kiln. On assessing the characteristics of different kilns through the most important trade names in the sector, and focusing on ventilation systems, by a comparison of the way kilns work, it may be concluded that they all exhibit a similar form of operation. The main difference lies in kiln size, which will condition the size of the motors for movement, ventilation and extraction.

In order to evaluate the behaviour of the installed fans in the face of power failures, a selection has been made of representative fans found in kilns.

Although the range of makes of kilns may be quite wide, this diversity is considerably narrower as far as ventilation systems are concerned. Grid II shows the results according to different models of installed fans.

The calculations were performed taking the following assumptions into account:

The fan works yielding maximum power at a certain speed.

There is a direct connection between motor and fan.

Solution intervals are obtained for the recommended fan working speeds.

Safety conditions are considered to be a fall of 80% in the work pressure, for combustion air as well as flue-gas extraction, which involves a drop of 55% in fan running speed.

Grid 2. *Fans for combustion products*

Model	Model 1	Model 2	Model 3	Model 4
K (kW/rpm^3)	11,1E-9	2,74E-9	4,48E-9	3.8E-9
PD2 (kgm^2)	27,9	9,9	19	15
I/K	0,62E-9	0,903E-9	1,08E-9	0.98E-9
P (kW)	15	22	22	4
[n_{min}-n_{max}] (rpm)	[600-1960]	[500-2180]	[900-1200]	[500-2120]
[p_{min}-p_{max}] (mm H_2O)	[50-600]	[10-400]	[40-500]	[10-400]
[Qmin-Qmax] (m^3/s)	[1,2-11]	[0,8-10]	[1,4-10]	[1,4-14]
Results				
tn_{max} (s)	11,6	9,83	12,56	11,046
tn_{min} (s)	24,6	42.8	27,9	46,83