ECONOMIC ESTIMATION OF CUSTOMERS POWER QUALITY PERTURBATIONS

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ABSTRACT: The liberalization of the energy market determined the growth of customers concerns supplied by various utilities regarding the quality of services provided. The customers became more conscious and better informed about the impact of electromagnetic perturbations on the electrical equipments and technological processes (inclusively on the quality of the final product) and, as a result, requested to the utilities to provide the electrical energy within the contracted power quality indices limits. Economic losses determined by interrupted manufacturing, damage of equipments, products of poor quality and time delays have raised the number of consumers not satisfied about the power quality degree. The level of these damages depends on the amplitude of the residual voltage and on the duration of the perturbation.

The paper deals with the survey of the supply continuity for customers connected to a medium voltage Italian feeder, and the estimation of the costs associated with these power quality disturbances. Starting from a certain acceptable level of the economic damages, a probabilistic method for estimating the admissible values of the power quality indices associated to supply continuity is presented.

Keywords: power quality, supply continuity, cost estimation

1. Introduction

The deregularization of the energy market determined the growth of customers concerns supplied by various utilities regarding the quality of the services provided. The customers became more conscious and better informed about the impact of power quality perturbations on the electrical equipments and technological processes (inclusively the impact on the quality of the final product) and, as a result, requested to the utilities to provide the electrical energy within the contracted power quality indices limits [1], [2]. Economic losses determined by the interrupted manufacturing, damage of equipments, products of poor quality and time delays have raised the number of consumers not satisfied about the power quality level [3]. The level of these damages depends on the amplitude of the residual voltage and on the duration of the perturbation. The growth of the number of devices sensitive to voltage variations and the possibility of

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malfunction of the electronic devices present in the control systems impose studies on various types of loads, for determining the perturbation amplitude – duration curves. For each equipment a limit curve amplitude – duration of the perturbation can be established, like CBEMA and ITIC (established for computers), but there are not curves that can be used for any type of equipment [4].

In this paper, the surveys conducted give an overview of the supply continuity for the customers supplied by the Italian power system. An esteem of the interruptions costs suffered by some facilities from the electronic products sector, small textile fibres, paper-mill, plastic matter industries is reported.

2. Supply continuity indices

The power quality indices characterizing the continuity of supply can be obtained using customer data and load data, monitored by the utilities. Regarding the reliability of supply, the standard IEEE 1366 stipulates a series of indices for quantifying the power system and customers interruptions [5]. These indices, for the case of system and customer interruptions, are:

- *SAIFI-System Average Interruption Frequency Index*

$$SAIFI = \frac{\sum N_s}{N_t} \tag{1}$$

where N_s is the number of customers impacted by a sustained interruption; N_t – number of customers supplied by the analyzed system; the sum is done for every interruption.

- *SAIDI-System Average Interruption Duration Index*

$$SAIDI = \frac{\sum (N_s \cdot D_s)}{N_t} \tag{2}$$

where D_s is the duration, in minutes, of a sustained interruption.

- *CAIFI-Customer Average Interruption Frequency Index*

$$CAIFI = \frac{\sum N_s}{N_a} \tag{3}$$

where N_a is the number of customers effectively affected by an interruption, at a specified moment during a year.

- *CAIDI-Customer Average Interruption Duration Index*

$$CAIDI = \frac{\sum (N_s \cdot D_s)}{\sum N_s} = \frac{SAIDI}{SAIFI} \tag{4}$$

It can be observed that two of the above indices characterize the number and average duration of sustained interruptions (*SAIFI* and *SAIDI*) that a customer may expect, while the other two (*CAIFI* and *CAIDI*) are reported to the effectively affected customers supplied by the power system.

Sag indices are needed for indicating the different performance levels and for guiding the utilities to appropriate design the ride-through alternatives of the customer equipments [6]. Some utilities are using new rms voltage variation indices for appreciating the power quality of the areas supplied, being applied for evaluating the entire distribution network or only one customer.

➢ $SARFI_X$ *–System Average RMS Variation Frequency Index*$_{Voltage}$

This index counts the number of voltage sags, swells and/or interruptions for a system. $SARFI_X$ corresponds to a number of voltage sags, swells and/or interruptions below a certain voltage threshold

$$SARFI_X = \frac{\sum_i N_i}{N_T} \tag{5}$$

where X is the rms voltage threshold, taking the possible values of 140, 120, 110, 90, 80, 70, 50 and 10; N_i number of customers experiencing short-duration voltage variations with amplitudes above X % for X >100 or below X % for X <100 due to measurement event i; N_T is the number of customers supplied by the analyzed system.

The following indices are subsets of $SARFI_X$:

➢ $SIARFI_X$ *– System Instantaneous Average RMS Variation Frequency Index*$_{Voltage}$

This index is defined for rms voltage variations with durations between 0.5 and 30 cycles.

$$SIARFI_X = \frac{\sum_i NI_i}{N_T} \tag{6}$$

where NI_i is the number of customers suffering instantaneous voltage variations with amplitudes above X % for X >100 or below X % for X <100 due to measurement event i.

$SIARFI_X$ is not defined for X equal 10 % because the standard IEEE 1159 does not define an instantaneous duration category for interruptions [7].

➢ $SMARFI_X$ *– System Momentary Average RMS Varition Frequency Index*$_{Voltage}$

It is defined for momentary rms voltage variations with durations between 30 cycles and 3 seconds for sags and swells, and between 0.5 cycles and 3 seconds for interruptions.

$$SMARFI_X = \frac{\sum_i NM_i}{N_T} \qquad (7)$$

where NM_i is the number of customers suffering momentary voltage variations with amplitudes above X % for X >100 or below X % for X <100 due to measurement event *i*.

➢ *$STARFI_X$ – System Temporary Average RMS Variation Frequency $Index_{Voltage}$*

$STARFI_X$ is defined for temporary rms voltage variations with durations in the range of 3 seconds to 60 seconds.

$$STARFI_X = \frac{\sum_i NT_i}{N_T} \qquad (8)$$

where NT_i is the number of customers suffering temporary voltage variations with amplitudes above X % for X >100 or below X % for X <100 due to measurement event *i*.

3. Survey results

The cost estimation is a difficult task [8]-[11]. The costs tend to increase with the sensitivity of the equipments and the widespread use of the microprocessor based devices. The costs due to poor reliability of supply are related with the outage duration, type of customer (industrial, residential etc.) and its nominal power. The cost data can be used for realizing the cost damage function of the customer, being the relationship between outage costs and duration. Interruptions of the electrical energy supply can determine the total damage of the plant equipment, the deterioration of the final product, extra maintenance costs or costs of repairs.

In Italy, surveys conducted in Northern and Middle Italy have reported the interruption costs suffered by industrial plants. The major part of the surveyed industries are in the electronic products sector, small textile fibres, paper-mill, plastic matter industries.

Supply interruptions, function of their duration, can cause various effects and, as consequence, economic damages of different entity. The long duration interruptions are considered the most dangerous. Their effects are the missed production for a total duration comprising the effective interruption period and process restarting time. In various industrial processes, the restoring time increases with the interruption duration due to the inertia of the devices involved. Fig. 1 shows the survey results of the impact of supply interruptions on customers processes, as function of their duration.

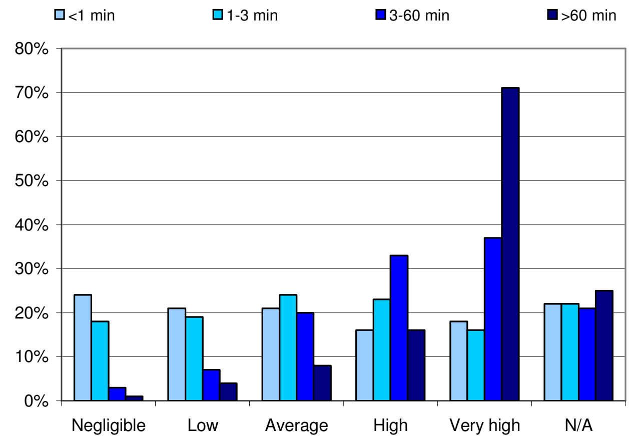

Fig. 1. Impact of the supply interruptions duration on the end-use customers

For the end-use customers very susceptible to supply interruptions, the short term interruptions can produce economic damages of the same magnitude as in case of long-term interruptions.

Another cause of the industrial processes interruption are the voltage sags. Many customers do not distinguish between micro-interruptions, voltage sags or interruptions, since the effect on the process is the same.

For the customers, the major effects of the power quality perturbations are the turn off and restart of computers and motors. As consequence the personal computers can be damaged and the lamps flicker occurs.

Fig. 2 shows the survey results in North and Middle Italy of the effects of power quality disturbances on customer devices and equipments.

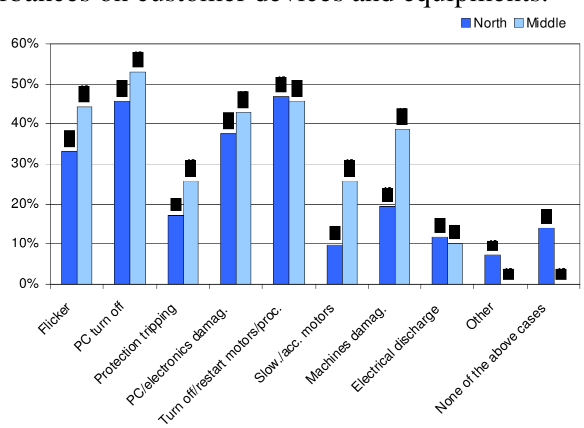

Fig. 2. Effect of power quality disturbances on customer devices and equipments

In Fig. 3 the survey results regarding the interruption of the industrial processes as a consequence of power quality disturbances are illustrated. As shown in Fig. 3, about 70% of the customers in Italy suffer at least one interruption of the industrial process during a year, as a consequence of power quality disturbances.

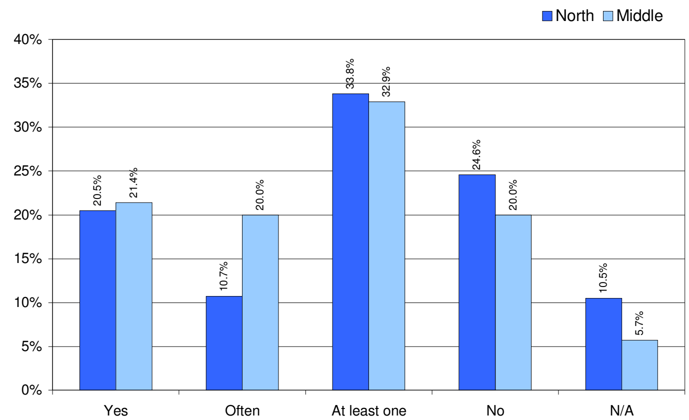

Fig. 3. Interruption of the productive process as a consequence of power quality disturbances

The power quality disturbances have a major impact in the plastic matter industries, metallurgy and small textile fibres industries. Instead, the wood processing industries are tolerant to the power quality disturbances.

In Fig. 4 shows the survey results of the qualitatively estimation of the interruption costs suffered by the customers during a year.

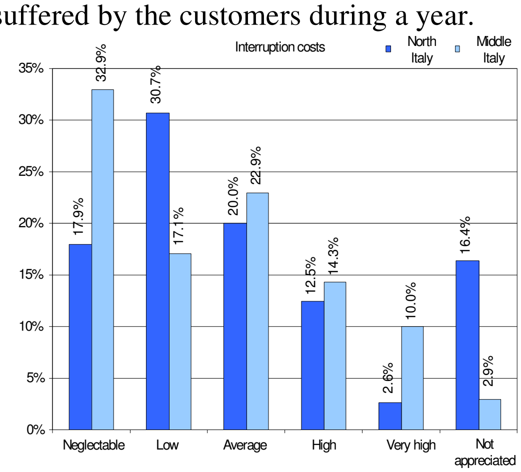

Fig. 4. Qualitatively estimation of the interruption costs

Fig. 5 shows the survey results regarding the qualitatively estimation of the costs, associated with other power quality disturbances, suffered by the analyzed customers.

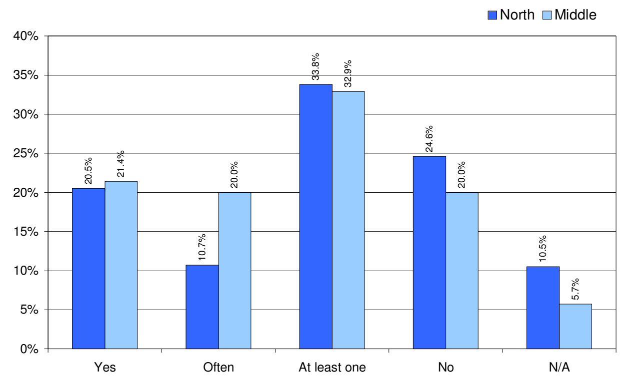

Fig. 5. Qualitatively estimation of the costs associated with the other power quality disturbances

About 40% of the industrial customers evaluate the annual costs caused by the power quality disturbances as a function of the contractual power, as reported in Fig. 6. The costs can quantify the global damage caused to the industrial process. Fig. 7 shows the specific costs for a single customer weighted as function of the contractual power.

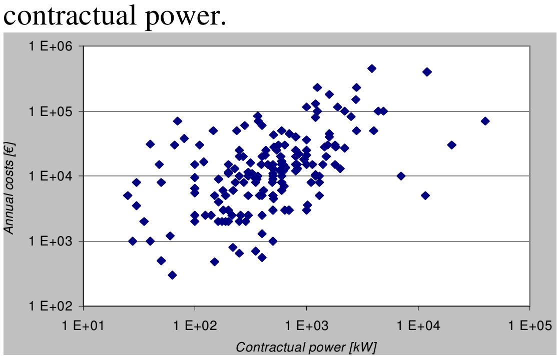

Fig. 6. Annual costs caused by the power quality disturbances

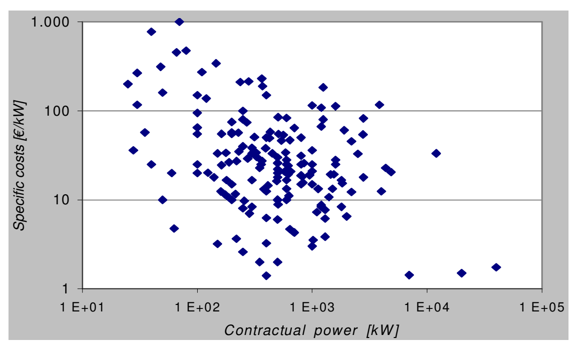

Fig. 7. Specific costs caused by the power quality disturbances

Fig. 8 shows the cumulative curve of the specific costs caused by the power quality disturbances. The costs are above 50 €/kW for about 30% of the surveyed customers.

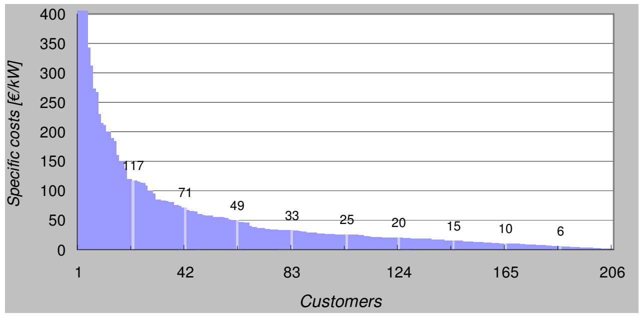

Fig. 8. Cumulative curve of the specific costs caused by the power quality disturbances

5. Conclusions

The power quality represents a complex and controversial problem. Its complexity lies in the set of factors that condition it and their interdependency. The power quality problems have a negative economic impact on the industrial processes. The estimation of the associated costs is a difficult task due the diversity of the phenomena disturbing the power quality. The surveys conducted in the Northern and Middle Italy have reported the interruption costs suffered by the industries from the electronic products, small textile fibres, paper-mill, plastic matter sectors. Also, the surveys report the costs caused by power quality disturbances as a function of the customer contractual power.

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