CONSEQUENCES OF INADEQUATE POWER QUALITY FOR INDUSTRIAL CONSUMERS IN SLOVENIA

Uros KERIN
University of Ljubljana – Slovenia
uros.kerin@fe.uni-lj.si

Andrej DERMELJ
Elektro Ljubljana – Slovenia
andrej.dermelj@telemach.net

Igor PAPIC
University of Ljubljana - Slovenia
igor.papic@fe.uni-lj.si

ABSTRACT

Power Quality is gaining importance. The growing awareness of the effect of poor power quality on the performance of industrial electrical networks is becoming a driving force for intensive research work on Power Quality associated phenomena and ways of reducing their impact. This paper presents research work involving investigation of poor Power Quality effects on organizations and industrial sites in Slovenia. The work was focused on the selection of the sites involved in the research, on determination of PQ-related disturbances affecting these sites and on the assessment of poor PQ-related costs. The investigation methodology was based on the on-site approach. Each investigated site was visited and correspondents were interviewed. For the interview, a special questionnaire was adopted.

INTRODUCTION

In this paper, the methodology of the investigation of Power Quality level is presented. It is based on the research work, in which PQ effects on organizations and industrial sites in Slovenia were investigated. The on-site approach involving questionnaire-based interviews was applied. The investigation was focused on determination of common PQ-related phenomena and their impact on organizations' overall performance; however the main goal was to assess the associated costs.

INDUSTRIAL ELECTRICAL NETWORKS

General classification

Industrial electrical networks are recognized as complex systems, comprising elements of electrical energy production, transmission, consumption and regulation. Considering the location, they vary in size and length of internal connections. In urban environment, networks are limited in size and are mainly cable-based. In city surroundings they extend on areas up to several dozen of hectares and include cable as well as overhead connections. Moreover, industrial networks normally combine several voltage levels, commonly in the range from 400 V to 110 kV and are used for supplying loads from several hundred kVA to 100 MVA or more. Network topology is meshed, however radial operation is also common. A sample case of the network is illustrated in Figure 1.

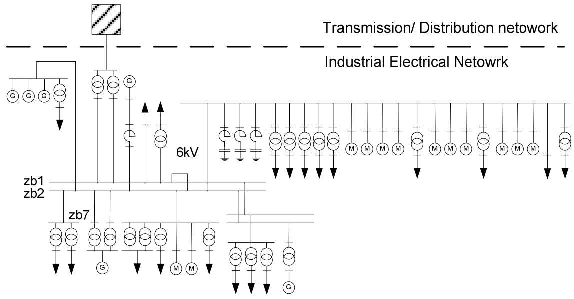

Figure 1: Sample case of industrial network

The network load characteristic is generally formed by diversity of machine types and special loads linked to the carried-out industrial processes, such as electrolysis or smelting. Therefore, the overall behavior of industrial networks can be defined as a result of individual behavior of each of its components including protection, monitoring and control equipment, and of their interactions [1].

Power Quality

Power quality of electrical networks is under continuous stress from various phenomena. In industry, the main sources affecting PQ are either power electronic devices, such as variable speed drives, processing equipment, computers, controllers and other; or every-day events, such as motor startups, capacitor bank switching, welding and other similar acts. As shown in Figure 2, these events impact network quantities in unique ways. In terms of PQ, these events are classified as short- or long-term disturbances involving voltage dips or swells, transients, harmonic distortion, under- or overvoltages, flicker, unbalance and others.

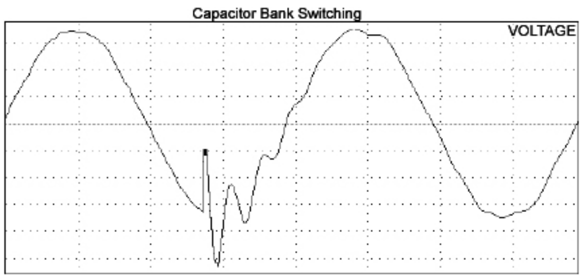

Figure 2: Voltage transient – short term disturbance

In modern industrial sites PQ is of great concern. Due to the competitive environment and the growing awareness of the economic effect of such events, industrial installations are being optimized by applying a range of solutions and preventive measures. The most common are back-up generators, voltage stabilizers, passive and active filters, multiple independent feeders and uninterruptible power supply (UPS) devices.

INVESTIGATION METHODOLOGY

The adopted methodology involved the on-site approach. Each investigated site was visited and correspondents were interviewed for their experience with PQ phenomena and their effects on performed activities. For interviews the questionnaire proposed by Leonardo Power Quality Initiative (LPQI) was adopted [2]. The questionnaire comprises 7 sections addressing the organization's general details and the site's technical performance (sections 1-3), and experienced PQ disturbances, their classification and impact on the organization (sections 4-7).
Since PQ is a relatively new term in power supply, many organizations still haven't realized its importance. Nevertheless, when a set of organizations involved in the investigation was formed, most of those who were invited to participate volunteered to cooperate. In all, 24 organizations with different manufacturing and service activities agreed to cooperate. In Table 1 their classification is given.

Investigated organizations	Nr.
Food and kindred products	4
Pulp and paper	3
Printing and publishing	3
Plastic and rubber	2
Metallurgy	2
Automotive	2
Cement	1
Transport	1
White goods	1
Pharmaceuticals	1
Oil or petroleum refining	1
Textiles	1
Insurance, broker &services	1
Chemicals	1
Sum	*24*

Table 1: Organizations involved in the research

Many of the listed organizations are among the largest in the sector. The number of employees varies from 50 to over 1000 with working time from 40 to 168 hours per week. Regarding contracted power, sites are divided into three categories: 0,5-2 MVA, 2-10 MVA and 10 MVA+, where two, ten and twelve of the listed organizations fit in respectively. Two sites are connected to the 110 kV voltage level (transmission network), while others are utility supplied (distribution network). Eight organizations have the annual energy consumption within the range of 1-5 GWh, six within 5-25 GWh while the other ten exceed the consumption of 25 GWh per year.
In the investigation, the phenomena of special interest were voltage dips, short 1-minute-interruptions, long 1-hour-interruptions, harmonics, surges and transients, flicker, unbalance, and electromagnetic compatibility. However, not all of the organizations involved in the investigation have experienced these phenomena or have a record of them. If this was the case, correspondents were encouraged to imagine that the event had actually occurred and to estimate the potential technical and financial impact of the expected consequences.

INVESTIGATION RESULTS

As a result of the adopted methodology, a comprehensive database comprising a range of investigation-related data was created. The data acquired were analyzed and classified according to the type of PQ event and the associated impact. The analysis essentially included two steps. Firstly, common disturbances affecting technical performance and consequent events were investigated. Secondly, the economic evaluation of these events was made. The results are presented in the following subsections.
Due to the nature of the investigation, the reader is advised at this point that the presented results are not adequate for drawing final conclusions and should be interpreted as indices rather than facts.

Events experienced and measures applied

Voltage dips and short interruptions have been identified as the most common disturbances affecting industrial networks in Slovenia. Based on the data analyzed, 50 % of industrial networks are affected by these on an annual basis, 37.5 % on a monthly basis and 4.1 % on a weekly basis. The percentage of organizations not experiencing these disturbances is 8.3 %.
According to the site correspondents the sources of poor PQ can mainly be found in "acts of nature" and utilities, nevertheless, they are aware of the effects caused by the equipment installed on-site. In most organizations electrical motors (55 %) are identified as main sources contributing to poor PQ; they are followed by electronic equipment (38 %), welding and smelting processes (20 %), capacitor switching (17 %), and processing equipment (13 %).

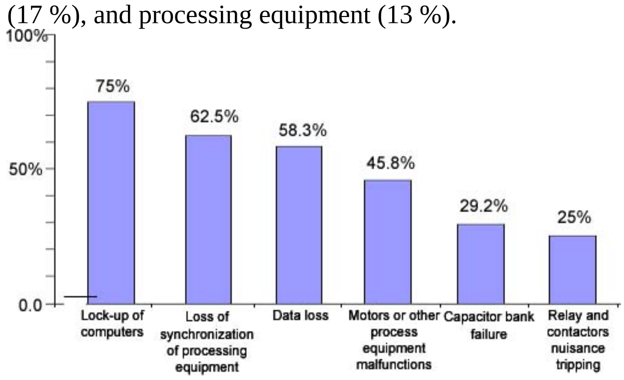

Figure 3: Reported consequences of experienced PQ events

Disturbances can result in mild or severe events. Regarding the data acquired, 75 % of disturbances cause computer lock-ups or damage to sensitive electronic devices (Figure 3). Less frequently disturbances cause loss of synchronization of the processing equipment (in 63 % of

events), loss of data (58 %), motors or other processing equipment malfunction (46 %), capacitor bank failure (29 %), and nuisance tripping of relays and contactors (25 %) of PQ-related events.
In order to reduce the effect of PQ and to prevent the potential production stop and the associated loss, various technical solutions have been applied to the installations. As most frequent preventive measures, UPS installations (84 % of measures applied) and two or more incoming power connections (70 %) have been reported. Also harmonic filters (54 %) and back-up generators have been commonly installed. However, just two of the listed organizations have additionally improved their power network with the installation of an on-site generation and one with the installation of a Static Var Compensator.

Financial impact

The supply of poor quality power directly affects ongoing industrial processes. Still, due to the comprehensive impact on various production levels the associated costs are difficult to assess. Therefore different aspects were considered in the evaluation, taking into account direct (equipment malfunction) and indirect costs (due to consequent unproductiveness).
Equipment affected by Power quality disturbance can cause a slowing down of a company's activity or a part of the production can run out of specifications. Due to equipment damage, necessary restarts, resets, and repeating operations the process runs at a reduced rate (i.e. speed, capacity) and cannot reach its nominal efficiency. Such a sequence of events creates direct costs, involving costs related to products running out of specifications and insufficient quality of products, and costs of equipment being damaged and those for additional maintenance.
As a consequence of equipment malfunction, indirect costs are formed, involving costs resulting from staff unproductiveness and wasted work in progress. Here, the idle time of the staff unable to work is evaluated, the costs of raw materials involved and inevitably lost are assessed, and the value of labor needed to make up for the lost production (e.g. overtime pay) is estimated. In addition, the costs of late delivery penalties, environmental fines and increased insurance rates are taken into account.
The presentation of results follows the categorization of the involved organizations given in previous sections, where categories regarding the annual energy consumption are presented.
Results are presented in the form of charts, providing the costs related to six PQ events addressed through study cases: voltage dips, short interruptions, long interruptions, harmonics, surges and transients, and flicker, unbalance, earthing and EMC.
Three sorts of charts are provided. The first one describes the financial impact on the organization reported for each case investigated (sum), while the second one stands for the costs of experienced events (real events) and the third one for the estimated costs as if the disturbance not experienced had actually occurred (estimation). In addition, a hypothetical evaluation was also made for the cases experienced, but without a firm reference to the financial impact caused e.g. flicker. In the analysis of the charts the costs of experienced events are addressed unless stated otherwise.
The financial impact is introduced as a sum of direct and indirect costs of all organizations in a certain category. By using this approach a clear overview of the impact on organizations of certain characteristics can be given on an annual basis with no deviation due to statistical processing. Nevertheless, one can still get related average costs by dividing the sum and the number of organizations included in each category.
The first category comprises eight organizations with the annual energy consumption in the range of 1-5 GWh. As provided by the charts in Figure 4, these are mainly subject to the costs due to voltage dips and short interruptions. Of all, three organizations have experienced voltage dips and have reported an associated loss of 180.000 € per year, while all eight have experienced short interruptions, in a sum causing an annual loss of 800.000 €.

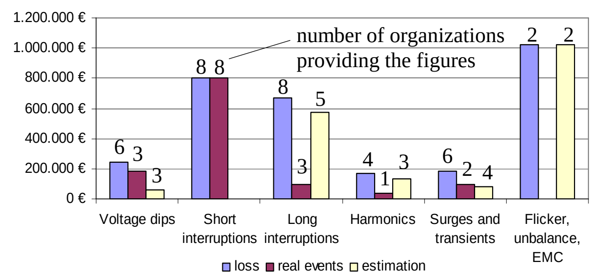

Figure 4: Annual costs related to category of organizations with annual consumption of 1 to 5 GWh (8 organizations)

Long interruptions have been experienced by three organizations, which reported an associated loss of 95.000 €. At the same time these have not been experienced by the other five organizations. These organizations have therefore estimated the loss as if it had actually occurred and provided an associated sum of 576.000 €.
As it is widely known, the financial impact of harmonics is not easy to define. Nevertheless, one organization claims to have 40.000 € of associated costs, three have estimated a potential impact of 130.000 € while the other four could not provide any figures.
Surges and transients are common phenomena causing costs in electrical networks. Two organizations experiencing them have reported an impact of 100.000 €. Moreover, based on a hypothetical evaluation of the rest of the organizations, an additional impact of 80.000 € is possible within this category.
For phenomena such as flicker, unbalance etc. only figures based on a hypothetical evaluation have been reported. However, the figures provided for the case are too extreme and can therefore not be interpreted as credible.

The second category comprises six organizations with the annual consumption in the range of 5-25 GWh. Based on the figures reported, this category is characterized by the organizations experiencing a high loss due to short interruptions. As illustrated in Figure 5, a financial impact of 1.380.000 € has been reported. On the other hand, these same organizations seem to have no problems with voltage dips. The fact is that most organizations have no adequate measuring equipment to distinguish between voltage dips and short interruptions. From the operation point of view restarts of equipment are needed in both cases, therefore some organizations recognize both cases as short interruptions and have probably reported incorrect figures.

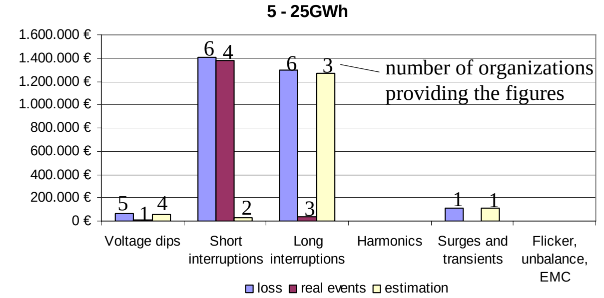

Figure 5: Annual costs related to category of organizations with annual consumption of 5 to 25 GWh (6 organizations)

Due to long interruptions the category faces an annual impact of 35.000 €. These interruptions usually affect a small part of production, however, if a larger part or even the entire production was affected, the impact would easily exceed 1.000.000 €.

Since a hypothetical evaluation of 100.000 € was provided for surges and transients, it is assumed that the category has no specific problems referring to the phenomena.

The third category comprises ten organizations with the annual consumption of more than 25 GWh. Based on the charts in Figure 6, the organizations in this category are subject to voltage dips and short interruptions. Due to the voltage dips, five organizations have reported an impact of 760.000 € and due to the short interruptions eight organizations have reported an impact of 950.000 €.

Organizations of this size usually have a meshed power network. Therefore, in case of long interruptions, they are able to transform the network topology in order to reduce the associated financial impact to its minimum. Reported impact based on experienced events involving long interruptions therefore equals 230.000 €, however if the worst case scenario should happen, a much greater impact, exceeding 7.000.000 €, should be anticipated.

The reported financial impact due to harmonics, flicker, unbalance and EMC, is provided on the basis of hypothetical estimations of three organizations.

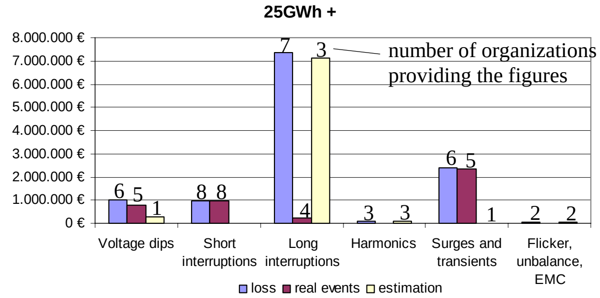

Figure 6: Annual costs related to category of organizations with annual consumption of more than 25 GWh (10 organizations)

In case of harmonics an impact equals 70.000 € while in other cases it equals 60.000 €. Meanwhile, the figures describing an impact due to surges and transients have been reported by organizations involved in steel industry. Due to welding and smelting performed, a number of equipment failures was experienced in the past, creating costs of 2.364.000 €. In order to avoid these costs in future, these organizations have already started reconstructing the sites.

CONCLUSION

This paper introduces an investigation of poor PQ effects on the operation of industrial sites in Slovenia. The summary of general characteristics of industrial electrical networks is given and common PQ disturbances affecting them are identified.

The investigation is based on the analysis of PQ related data reported by the organizations involved. The analysis was made on an annual basis, using basic methods for statistical processing. According to the figures reported by twenty-four organizations involved in research, a rough conclusion can be made that industrial networks in Slovenia are mainly subject to short interruptions and voltage dips, in sum creating an annual financial impact of over 3.000.000 €. However, since the nature of such investigations is known for its misestimations (under- and overestimations), the accuracy and credibility of provided results could be a subject of further discussions.

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