PRACTICAL SOLUTIONS FOR THE SHUTDOWN PROCESS IN INDUSTRIAL FACILITIES DEPENDING ON NETWORK DISTURBANCES

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SUMMARY

The report describes a series of activities carried out in the three-year period 1998/2000 by CESI and the former research Division of ENEL at some Italian industrial facilities with a view to reducing the damage caused to the production process by unscheduled stops of the production line following interference in the electrical power supply.

The companies where the activities described in the present report were carried out concern mainly the following product sectors:
- textile industry
- building material industry
- electronic industry
- glassware industry

The activities consisted of experimental measurements, studies and, in some cases, operations that subsequently enabled the production equipment to be desensitised, that is, the annual number of unscheduled stops following electrical power supply interference to be reduced considerably.

For each activity, the paper provides a brief summary of the problems that arose, the solutions found and the time required for the service. Each servicing operation was performed by taking the following steps in the order specified:
- monitoring of voltages and currents for preset periods both at the interface with the mains and in typical sections of the internal factory network
- identification of the section the plant sensitive to interference (mainly voltage sags and microinterruptions)
- design of corrective action and, in some cases, its implementation.

The cases described in the report refer to different production cycles and, despite this, susceptibility to interference mainly concerns similar types of electromechanical equipment: direct and alternating voltage motor drives, logic controllers, asynchronous motors, automation logic.

The most frequent and problematic types of mains power interference are also mainly attributable to voltage drops of over 50% and lasting more than 50 ms or micro-interruptions lasting for between 200 and 500 ms.

The condition described above makes it easier to solve the problem of improving the quality of the supply in that a limited number of methods for desensitising the equipment can be elaborated and implemented quickly and inexpensively on the site.

The expected follow-up is to provide the manufacturers that construct industrial equipment with useful indications on how to design equipment in such a way that it is already immune to the frequent mains power interference.
INTRODUCTION

Power supply market liberalisation as well as an increase in the user equipment sensitivity to network disturbances lead to a growing requirement for high quality and power supply continuity. CESI has been working for a long time in co-operation with ENEL experts of the former Research Division now incorporated into CESI in the quality supply field on any topic providing for monitoring and improvement (1), (2), (3), (4). In other words:
- Definition of the network and interface standards with any user equipment.
- Disturbance type definition.
- Survey methods in the field of disturbance by means of dedicated instruments.
- Susceptibility analysis of user equipment inclusive of laboratory testing, analysis simulation and field analysis.
- Screening method study relating to user equipment both through specific interventions on end user equipment and by fitting continuity external control devices (uninterruptible power supplies etc).

The paper partially summarises the on-site activity at some specific industrial facilities aiming at desensitising user equipment from voltage dips and short-interruptions by means of measures of low impact and cost for the end-users.

Surveyed disturbance types lead to voltage dips and short-interruptions, the commonest and most widespread and dangerous disturbance type as far as the end-use equipment operation is concerned. The activity described here below was essentially fulfilled in a glassworks, a cement factory, a textile company and an electronic industry (CD production). Only a few examples of interventions by CESI experts and chosen among the most significant and valuable case studies, easily representing and applying to different medium-size companies.

ON-SITE SCREENING INTERVENTION

Glassworks

A significant intervention is that carried out within well-known Italian glassworks, manufacturing hollow glass. Tests were carried out at one Group plant in Lombardy supplied by the 130 kV network. The management complained about production damages depending on voltage sags and short interruptions of the network voltage. More precisely unattended stops and mechanical damages were reported to the air compressors, driven by big three-phase asynchronous motors. In other words, on the occasion of the short interruption, should the compressor blades still revolve, when the network voltage is recovered, the transient torque on the asynchronous motor is excessively consistent, leading to a possible damage to the coupling joint between the electric motor and the compressor.

In order to check and analyse the described inefficiency during May-October 1999, ENEL together with CESI carried out measuring surveys within the factory.

The intervention was mainly divided according to the following operating modes:
- Installing and setting, at delivery site, an EQUA recorder, which should check voltage quality according to the CEI EN50160 standards.
- Installing and setting, on the asynchronous motor terminals of a 280 kW compressor, another EQUA recorder which should detect possible transient three-phase power supply downstream the main remote control switch.

During the six months of the measuring survey, the power supply quality turned out to be satisfactory, according to the standard requirements, as only once the surveyed compressor stopped because of a voltage loss. On Figure 1 the progress of voltage and current after the disturbance.

A stator voltage consequent to the residual flux was clearly detected.

It is however important to remind that voltage is supported by power factor correction capacitors directly connected to the compressor motor.

Entering into specific details as far as the motor-driven compressor wiring diagrams are concerned, it was remarked that the most sensitive unit to disturbances is represented by the electro-mechanical switch whose setting and opening was delayed by the glassworks Technical Management especially to avoid opening during voltage sags. Such a delay, however, keeps the switch on during short interruptions leading to a parallel not synchronized between the stator residual voltage and the network voltage when recovered followed by a current peak whose electro-mechanical transient torque can lead to the motor shaft joint break.

To overcome the problem it was decided to design an ancillary device to install onto the switch control circuits, aiming at increasing immunity to voltage sags and micro interruptions. On Figure 2 a diagram of the device operating principle. It is basically an electronic
relay which distinguishes network sags from network micro-interruptions; a small UPS is included in the device to feed the control circuits of the air compressor. In the case of a voltage sags, the UPS provides for the power supply continuity to the control circuits (in the case of the glassworks, it is nothing but the opening reel of the control switch).

In the case of any short interruptions, no more voltage is supplied to the control circuits and the control switch is opened: under such conditions when voltage is recovered, it is possible to avoid the dangerous lack of voltage synchronicity as above described. The automated device starts up the stopped electro-compressor within a defined time lag, under normal conditions.

What deserves mentioning is that such a device project was based on the experimental detection of the sensitivity curve of the electric compressor control units (control switches) (Figure 3), using a voltage sag and micro-interruptions generator instrument simulating the disturbed network behaviour.

The instrument was designed and manufactured by the former Research Division of ENEL now incorporated into CESI and a short description of it is enclosed in the Appendix. Tests prove that remote control switches and additional control units are insensitive to short-interruptions lasting for less than 55 ms and to any voltage sag whose residual voltage accounts for not less than 55%.

Tests were later repeated under the same modes, but introducing the specific device described in Figure 4 on the asynchronous motor control circuits. A consistent increase of immunity to voltage losses and micro-shutdowns was reported.

**Cement factory**

A different example of the diagnostic activity carried out and enforced by ENEL and CESI is represented by a cement factory in Lombardy, whose electric energy is supplied through one feeding line at 66 kV (isolated neutral).

The installation consists of a rotary oven with two raw material and end product grinding mills, respectively upstream and downstream. Fumes coming from the oven are purified through an electrostatic filter system at 70 kVcc: the first electric fan, whose power accounts for 1100 kW (driven by a d.c. motor) removes the oven fumes and send them to the filter. The second electric
fan, always driven by a d.c. 200 kW motor, allows to remove ashes from the filter, sending them to the stack. The installation is managed by an industrial PLC interfaced by nine I/O analogue and digital cabinets.

On the occasion of the network disturbances (voltage sags and short-interruptions) often the installation stops, thus leading to heavy consequences to production and especially to the environment because of the emission of ashes from the oven stack. This can be easily explained because electrostatic filters are no longer supplied enough due to the voltage shutdown, while electric fans are still inertial operating, thus sucking fumes from the oven and sending them to the stack. During the survey by the CESI, it was remarked that no control or monitoring device was equipped with a buffered preferential power supply. It was suggested a series of solutions aiming at improving productions. The specific measures referred mainly to two different disturbances:

- Voltage sags
- Micro-interruptions

Long-lasting shutdowns could only be solved changing the configuration of the 66 kV feeder from one feeding line to 2 feeding lines and especially fitting an automated closing function on the power switch of the primary cabin-side line. Such a measure allows to partially cut long-lasting shutdowns, which are turned in the most cases into micro-interruption, lasting for about 500 ms. As for voltage sags, the detailed analysis of the installed equipment proved that any control electronic cabinet consists of a single-phase transformer deriving from a three-phase dorsal at 400 V, whose ratio accounts for 400/110 Vca. A buffered power supply is easily feasible simply fitting a three-phase UPS in series to the existing power supply dorsal at 400 V.

- The UPS power accounts for 20 kVA. Such a change allowed to cut rejections to voltage sags and to short-interruptions up to 500 ms as any device, PLC cabinet and fan driving controls were duly fed. The lack of power supply to electrostatic filters, which is impossible to avoid during the 500 ms, did not lead to any environmental problem depending on the ash discharge duly taking into account that the phenomenon is not at all consistent.

**Textile company**

A different diagnostic action was enforced within a textile company weaving yarns, MV fed. This company too complained about stops to the production cycle. After monitoring the existing installations, it was possible to come to the conclusion that there were two types of machinery sensitive to disturbances:

- Contactors controlling the small-size asynchronous motors
- Single-phase electric drives for small-size asynchronous motors.

As for contactors, it was suggested to the company Management to delay opening by about 5 seconds. Such a delay allows, in fact, to desensitise the installations. The situation as for the single-phase electric drives operating on the weaving yarns was far more critical. Mainly any drive is equipped with different motors, among which the main motor is meant for the reeling and the others to different additional processes (Figure 5).

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- The machine most sensitive unit consisted of the main motor drive (2.2 kVA): any desensitisation has to apply to such a unit;
- The machine, under testing conditions, is not excessively sensitive to voltage sags as, statistically, the higher number of voltage sags on a MV line leads to a residual voltage higher than 60%. It is however extremely sensitive to micro-interruptions. What is more 90% of such micro-interruptions on a MV line lasts for more than 0.4 s.

Two alternative solutions were suggested for desensitise:

a) Installation of an uninterruptible power supply (UPS)

When duly installing similar equipment, it is possible to actually totally mitigate immunise critical processing cycles from any network disturbance, permanently powering any sensitive machine through the UPS.

During sizing the following issues are to be taken into account:
- even though machines to be desensitised are fed by means of a three-phase power supply, practically their power absorption is single-phase. It is therefore necessary to preliminary redistribute loads on the three-phase line;
- the inverter size must be chosen according to the peak current (not to rms value).

b) Installation of a dedicated electronic device

Such an alternative implies
- the installation, at the input of each machine to be desensitised, of the previously described electronic device (Figure 2), which can discriminate the presence of the power supply sags from short interruptions, even in the case of loads which can supply reverse voltage (for instance, asynchronous motor locally power factor corrected);
- connection to the “stop-start” circuits, already on the machine, of the specific device, which in the case of a short-interruptions and within the drive immunity time (in the specific case, at full load, for about 4 periods), sends a control signal thus leading to a untimely production process stop, that is to say a controlled speed stop;
- a control on the specific function of the installed device.

Such a solution, even though it does not allow to avoid stopping the machine, could allow to get rid of any costs and problems depending on scrap and waste pieces and on necessary time periods to recover initial settings, mainly severe conditions after an abrupt stop and not entirely controlled on such a production cycle.

Electronic industry

The last described case study refers to a company manufacturing CD-ROM, fed by 2 feeding lines and through its own stepping down cabin. (MV/LV)

This customer too complained stops in the production cycle in conjunction with typical network disturbances: micro-interruptions and voltage sags.

After an accurate survey on the user equipment, it was possible to identify a machinery which not only stopped during disturbances, but also suffered the breaking of the electric motor of a vacuum pump. Possibly the break depended on the operation of the automatic closing switch of the MV line and more precisely to the power supply recovery after the micro-interruption.

The asynchronous motor which was still operating reached a voltage spike depending on an incorrect synchronicity with the network voltage.

To check the types of disturbances on the MV power supply line, an EQUIA analyser was installed at the customer site. The recorder was installed and used for three months in autumn 1999. In Figure 7 a detailed description of the monitoring arrangement in the factory.

![Fig. 7 Typical arrangement to check the power quality at an industrial site](image)

During the entire recording, 20 events were recorded, and they totally complied with events recorded at the ENEL Centre controlling the substation feeding the MV line under survey.

For some of them it was possible to classify their nature and origin. In table 1 a detailed list of the recorded events.

<table>
<thead>
<tr>
<th>No. of the event</th>
<th>Day</th>
<th>Date</th>
<th>time</th>
<th>Diagnostic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Monday</td>
<td>04/10/99</td>
<td>05.59.58</td>
<td>Connection of MV bank for pf correction</td>
</tr>
<tr>
<td>2</td>
<td>Tuesday</td>
<td>12/10/99</td>
<td>09.46.14</td>
<td>Tripping of the ground fault protection</td>
</tr>
<tr>
<td>3</td>
<td>Tuesday</td>
<td>12/10/99</td>
<td>10.04.18</td>
<td>Tripping of the directional protection</td>
</tr>
<tr>
<td>4</td>
<td>Monday</td>
<td>18/10/99</td>
<td>19.40</td>
<td>Long term interruption</td>
</tr>
<tr>
<td>5</td>
<td>Saturday</td>
<td>13/11/99</td>
<td>14.01.43</td>
<td>Voltage sag on the MV bus-bar</td>
</tr>
</tbody>
</table>

Table 1- Disturbances recorded in the HV/MV step-down station

The suggested measure still consists of the installation of a voltage relay discriminating voltage sags and
micro-interruptions as previously described, leading to the machine stop and then to the electric vacuum pump stop followed by the opening of the cut-out switch which avoid the motor casual repeated synchronicity when voltage is recovered. Such a measure, even though it does not prevent the machine from stopping, allows however to protect its integrity.

APPENDIX
Equipment used to generate voltage sags and micro-interruptions
The equipment and patented by CESI was manufactured according to the principle diagram on Figure 8.

Switch I is made of IGBT transistors, the L-C filter allows to get rid of any high frequency switching spikes and the control board allows to generate voltage sags and micro-interruptions of various width and duration. It is possible to generate voltage sags whose width can be programmed, up to 100% of the instantaneous input voltage value and whose duration varies at ease between 1 ms and 10 seconds.

Short-interruptions start can be programmed at ease starting from the network voltage zero up to 20 ms. A voltage sag can be produced on a single phase or three phase at the same time and its depth can totally varies according to each single phase.

On Figures 9 and 10 there are a series of typical disturbances generated by the above said device: a 20 ms short-interruption and a sag with a residual voltage of 40%, lasting for 300 ms.

CONCLUSIONS
The desensitising experience on end-user equipments allows to come to the following conclusions:
- notwithstanding the high variety of production cycles, sensitivity to disturbances mainly affects similar electro-mechanical devices: d.c. to a.c. motor drives, asynchronous motors, logic controllers, automation logic.
- the most frequent and dangerous network disturbance types essentially depend on voltage sags whose depth accounts for more than 50% and lasting for more than 50 ms or on micro-interruptions lasting between 200 and 500 ms.

Such a conclusion allows to simplify the problem solution in the case of the power supply quality improvement, as it is possible to define a limited number of desensitising methods on different equipment which can be easily and rapidly set on site at convenient costs for the customer.

REFERENCES