Power Quality Application Guide

LEONARDO POWER QUALITY INITIATIVE

Voltage Disturbances

Voltage Sags in Continuous Processes

Case Study

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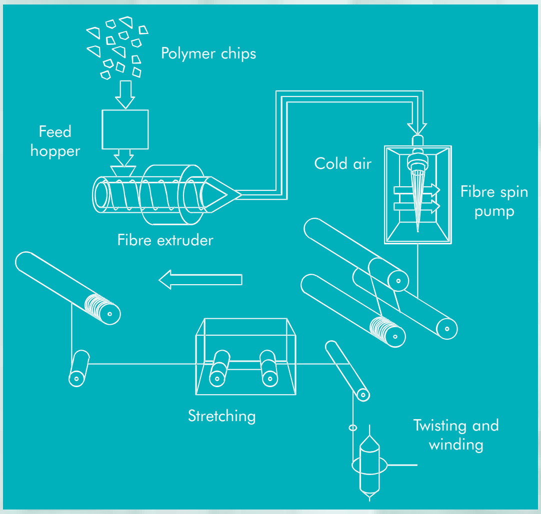

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Voltage Disturbances

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Voltage Sags in Continuous Processes - Case Study

Dipl-Ing Marcel Didden
Katholieke Universiteit Leuven
June 2003

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Voltage Sags in Continuous Processes - Case Study

Introduction

This section describes a voltage sag case study in Belgium. One of the industrial processes well known for being sensitive is the extrusion of plastics in the textile industry. In this process, plastic chips are melted, transformed into filaments and finally wound onto drums. The fibres can be used to make, for example, carpets. Belgium is the largest exporter of carpets in the world and the second largest producer after the USA.

In order to obtain a clear understanding of the size of the voltage sag problem in Belgian extrusion companies, a survey was conducted among nine users of this process. In this study it was found that the average annual number of production disruptions due to voltage sags was four. We conducted a thorough audit at one of these companies. The following three topics will be described:

- the production process
- the financial loss due to a forced production stop and the configuration of the electricity network
- possible solutions that mitigate damage, considered from both technical and economic viewpoints.

Problem analysis

The company examined operates three processes that are vulnerable to voltage sags: Bulk Continuous Filament (BCF), Continuous Filament (CF) and Heat Set. In this document, we discuss the behaviour of the BCF process.

The production process

Figure 1 shows the main sub-processes in a BCF extrusion line that produces textile fibre from polymer chips. The following steps can be distinguished:

- The *extruder* melts the chips into a homogenous substance
- The homogenous substance is pushed into a device that contains small holes (called a spin pump), resulting in a fibre (*melt spinning*)
- Finally, the fibre is *stretched, twisted and wound* onto the spools.

To perform each of the above processes, several drives are used.

Simply from looking at the specifications of the drives and from communicating with the manufacturers, we already come to some interesting conclusions. All drives that are used in the chosen textile company originate from different manufacturers and have their individual voltage sags immunity characteristics. In general, this immunity level does not significantly exceed the compatibility level of 90% (retained voltage) stated in the standard EN 50160.

If one of the components trips due to a voltage sag, the entire process will be disrupted. This implies that the weakest link determines the process behaviour towards voltage sags and all components must be investigated separately.

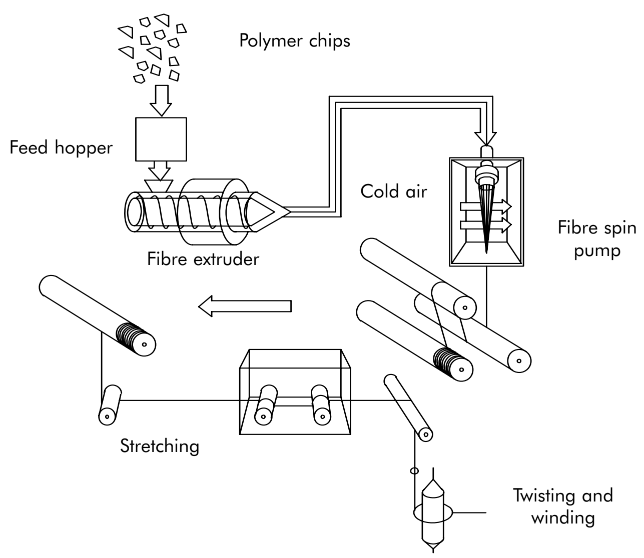

Figure 1 - The textile extruding processes

Manufacturers of textile extrusion machines also offer production lines with explicit immunity to sags. We did not investigate this option in detail, since this case study was conducted on an existing production line.

The first component, the extruder, is driven by a DC motor. The motor is equipped with an analogue variable speed control. In order to protect the power electronics in the drive, the undervoltage protection is set at a very sensitive level. It will block the entire process whenever it registers a voltage drop of 20% or more in one or more of the phases.

The spin pumps are equipped with a variable speed drive. The undervoltage protection of these drives will block the process if the voltage of the DC bus drops by 15%. Reference [4] shows that these appliances are always sensitive to three-phase sags and sometimes to one or two phase sags.

The stretching, twisting and winding is performed by variable-speed drives that are fed from a common DC bus. These drives are equipped with kinetic buffering: the motors act as a generator during the sag and feed energy back to the DC bus.

We conclude that both the drive of the extruder and the drive of the spin pump have to be taken into account when looking at mitigation methods.

Two further possible points of concern are process air and electronic process controls. Our investigation will show that it is not necessary to study this in further detail.

Financial damage

Immediately after a sag which halts the process, the workforce begins to restart the process lines successively. Depending on the number of production lines (typically 10 to 20) the entire process is resumed after two to four hours. This means that the average production outage ranges between one and two hours. There is no decrease in the use of raw materials during these four hours, because the extruder itself will be started immediately after the sag. If the extruder were not started immediately and the molten material were allowed to stay in the extruder, it would burn on re-heating and the burned particles will come out of the extruder gradually, over a period of several days, resulting in poor quality product. The cost of such a burn, therefore, would be much higher than that of discarding the excess polypropylene after extrusion. Furthermore, the workforce clean the devices themselves, so there is no increase or decrease in labour cost.

A major influencing factor concerning the financial loss is whether or not the factory production is continuous. In continuous production, as practised by this company, the production lost during downtime cannot be recovered by working extra time, so loss of production translates directly into loss of profit – that is, the loss is equal to the value of the product not produced as a result of the

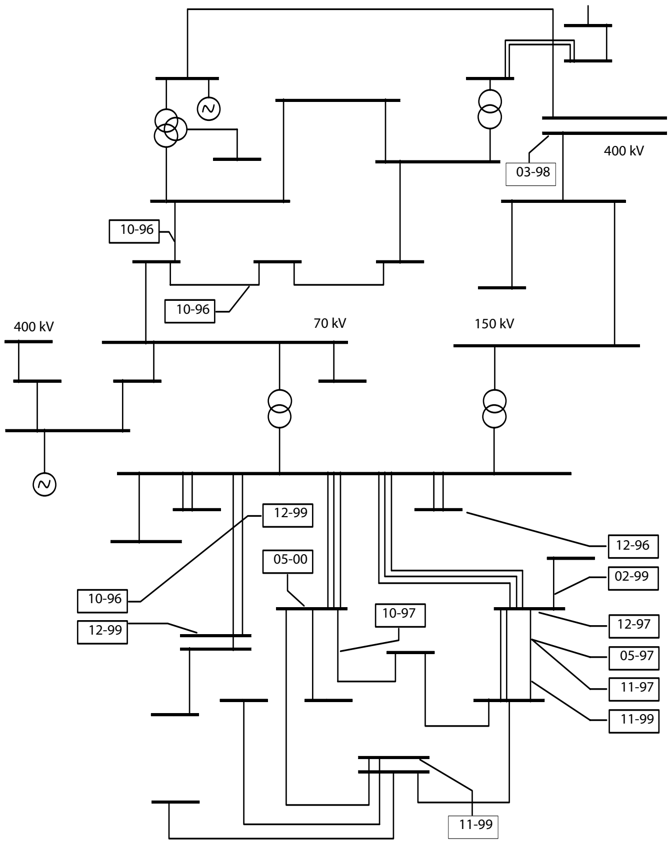

Figure 2 - Single line diagram of the electricity network

(The squares show the geographical origin and dates of the faults) downtime. In a non-continuous process, lost production can be recovered by overtime working, although there may well be additional labour costs.

Electricity network and origin of the damages

Figure 2 shows the electrical network in the vicinity of the investigated extrusion company.

The network is modelled up to the three connections to the 400 kV transport grid (indicated by dashed lines). The labels show the location and the dates (month/year) of the faults that have led to a process interruption during the monitoring period of 3.5 years. It can be seen that faults in the 15 kV distribution network cause most of the process halts. A sag meter installed at the electrical entrance of the extrusion company shows that most disturbances are three phase faults. Comparing the process interruptions with the output of the meter shows that the equipment is not vulnerable to three phase faults leading to dips with a retained voltage above 84%. Looking at the product specifications of the components, we conclude that the variable speed drives are certainly weak parts of the process. One of the possible explanations for the high occurrence of three-phase faults is excavation work for construction in the adjacent neighbourhood.

Area of vulnerability

The concept 'area of vulnerability' (e.g. [5]) is used to visualise the retained voltage at the extrusion company due to a three-phase short circuit somewhere in the network. Figure 3 shows this area of vulnerability for symmetrical three phase short circuits. Since it is these faults that cause most of the process interruptions, we do not have to use a sophisticated classification of voltage sags as described in [1]. For example: a cable or busbar in this network situated in the grey area of 50-75%, indicates that a three phase short-circuit at this cable or busbar will lead to a voltage sag at the extrusion company with a retained voltage between 50-75%.

Since the drives of the extruders and the drives of the spin pumps are vulnerable to short circuits with a retained voltage smaller than 75%, we can conclude that a large part of the distribution network is situated in the area of vulnerability of the extrusion company. This has to be taken into account when investigating mitigation methods.

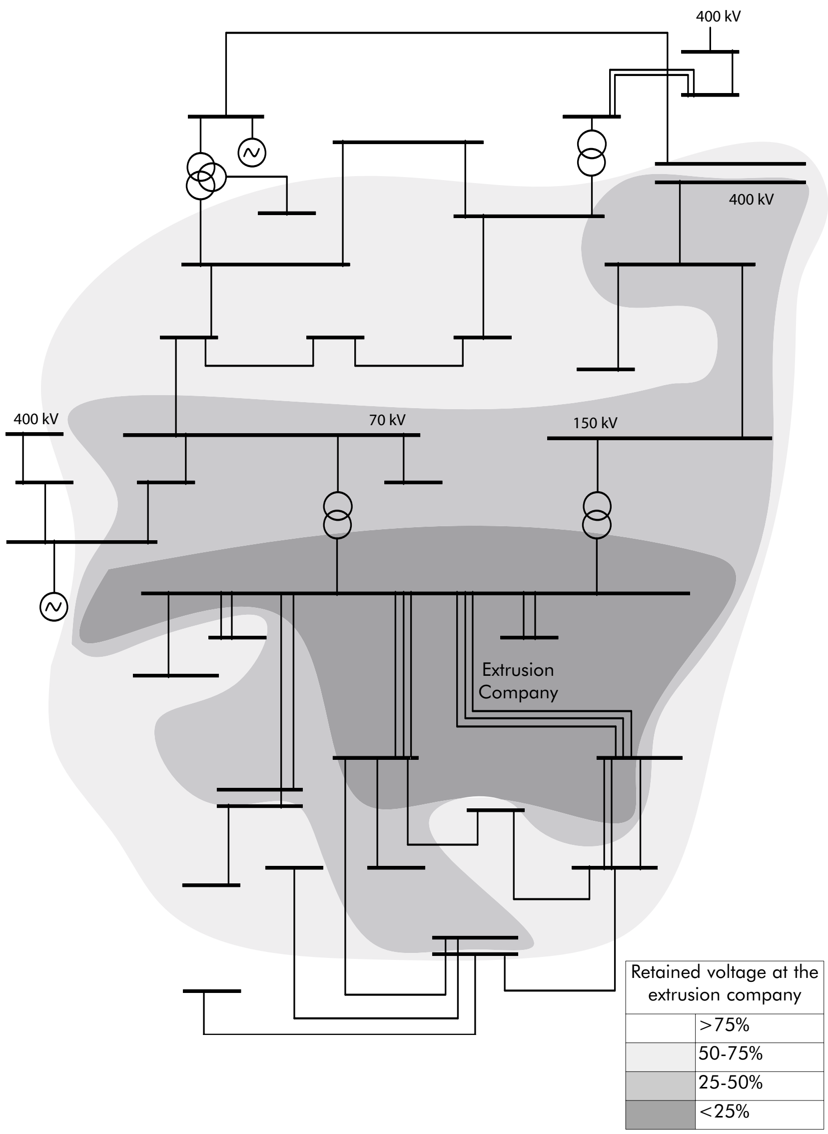

Figure 3 - Area of vulnerability

Mitigation methods

Looking at mitigation methods we refer to a block diagram introduced in [5] (Figure 4).

The four possibilities in this figure are investigated in the next sections.

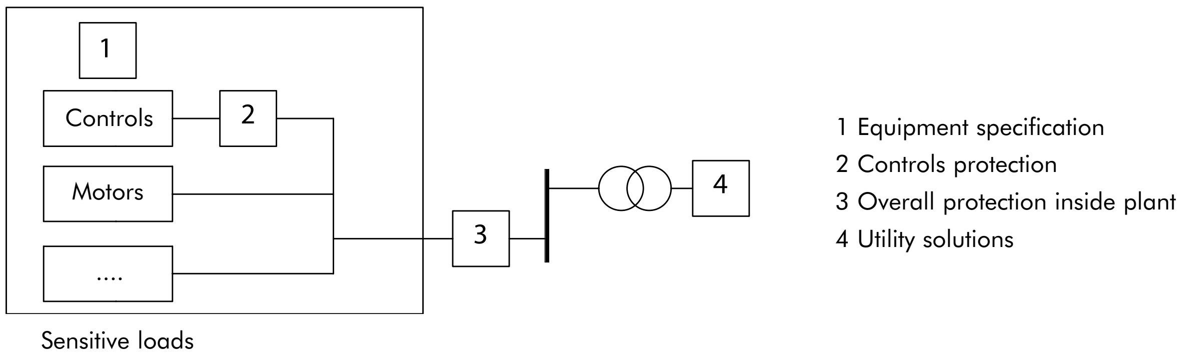

Figure 4 - Solutions to decrease cost due to voltage sags [5]

Equipment specification/controls protection

Before altering the equipment, it is important to make an inventory of all parts of the process that are vulnerable to sags. The fact that one piece of equipment trips first, does not indicate that all other items are immune to sags and there is a high risk that some other piece of equipment may trip once the most sensitive part has been protected. From the last paragraph we conclude that we certainly have to look at both the drives of the extruders and of the spin pumps. We must be aware that protecting only these drives does not guarantee a significant decrease in the number of interruptions due to sags since other parts of the installation can become the weakest link.

After communication with the manufacturer of the spin pump drive, we learned that it is not possible to alter the drive as it is an analogue design and changing characteristics such as protection settings requires hardware changes. Due to the fact that the DC bus of the variable speed drives is not accessible from outside it is not possible to support this bus, for example with a boost converter [6] or an active front end [7]. Furthermore, from the manufacturer of the entire extrusion line we received the information that the drive cannot be exchanged for another due to software conflicts. It can therefore be concluded that further investigation in this area serves no purpose.

Protection inside the plant

Several possible methods of protecting the system entirely or partially were investigated. The entire system has an apparent power of 1,625 kVA. Because 955 kVA is only for heating purposes, we also investigated the protection of the process which drives the system. When only part of the system is protected, an additional static switch has to be installed, resulting in the topology of Figure 5. We first investigated the use of an Uninterruptible Power Supply (UPS) in the form of a flywheel with a diesel engine.

Secondly, we investigated other systems that only protect against voltage sags but not against outages. Examples of these systems are:

- *Dynamic Voltage Restorer (DVR):* A DVR only adds the missing voltage to the voltage of the network (e.g. [8]).
- *DySC:* A DySC is a power electronic device containing a series sag corrector and a shunt converter that provides voltage sag immunity with a minimum retained voltage of 50% and 2 s, which covers 92% of the voltage sags that have been reported in a large study sponsored by EPRI [3].
- *Flywheel:* A flywheel without a diesel generator protects the equipment against all sags as long as the inertia of the flywheel can support the load. Most flywheels can supply the rated load for 3-15 s, which is sufficient to protect against all voltage sags but not against supply outages.

The purchase prices for all the above mentioned sag mitigation equipment do not vary substantially. However, one should take into account the costs of annual maintenance and stand-by losses and, in that case, the DySC has the lowest cost. Taking into account that all recorded sags had a retained voltage exceeding 50%, we can conclude that all the above mentioned systems would have protected the process against these sags.

We also investigated the use of separate UPS devices for all the drives. This turned out to be far more expensive than the other options due to the large amount of power electronics.

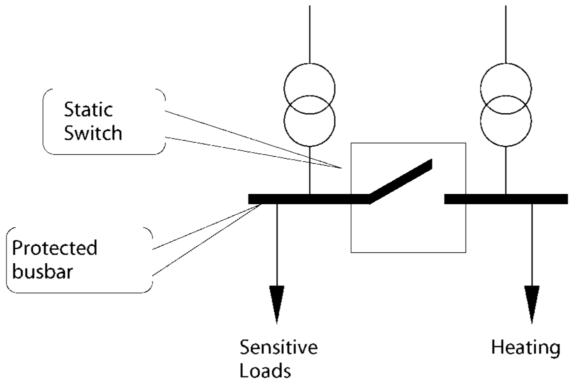

Figure 5 - Protecting a part of the process

Utility solution: changing the electrical network

Process outages can also be avoided by altering the network area. We examined two possibilities:

- adding a 10 MW generator
- restructuring the network configuration.

The addition of a generator will uphold the remaining voltage with:

$$\Delta U = \frac{S_g}{S_k} \cdot \cos(\alpha - \phi) \cdot 100 \qquad [9]$$

where

ΔU is the voltage increase in % of the rated line voltage

S_g is the rated generator power

S_k is the short circuit power

α is the phase angle of the short circuit impedance

ϕ is phase angle of the generator current.

A second option is to change the grid connection. In this option, the company would be connected to another feeder, separated from the neighbourhood.

Both possibilities are visualised in Figure 6.

By comparing Figure 3 with Figure 6a, it can clearly be concluded that adding a generator of 10 MW will not help greatly. However, restructuring the grid (Figure 6b) will alter the area of vulnerability, ensuring that there will be no more damages by voltage sags in the distribution system at 15 kV. An additional advantage is the fact that this restructuring will not only protect the BCF process but also the other two earlier mentioned processes (CF and Heat Set).

Since network adaptations were to be made by the network operator for other reasons, only the additional cost of separating the two busbars are billed to the extrusion company.

Economic analysis

When the different options are compared, two cost terms must be taken into account:

- the cost of losses attributable to voltage sags, bearing in mind that even after protective measures are taken, some reduced risk will still remain
- the cost of the protection measures.

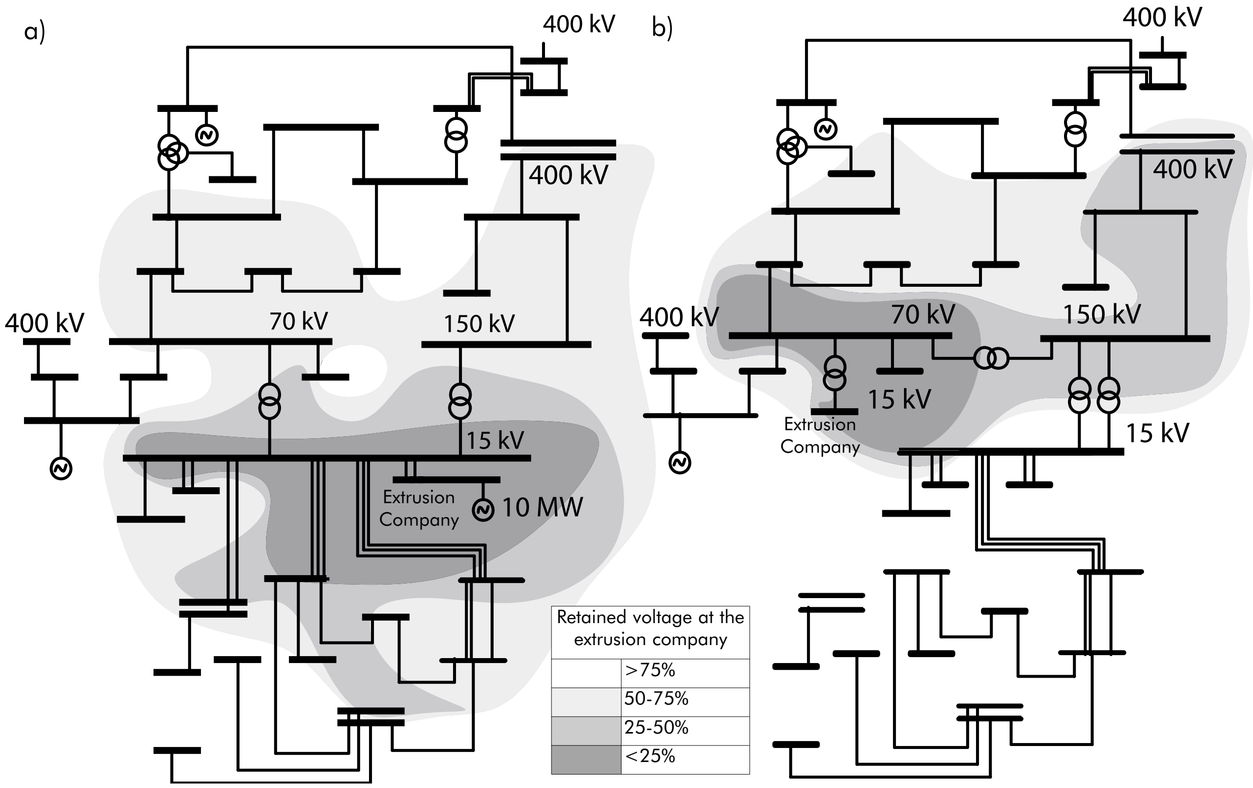

Figure 6 - Area of vulnerability

a) Adding a 10 MW generator
b) Changing the network structure

Whether or not a solution is seen as cost-effective also depends on the economic criterion that is used to evaluate the solution. This will be expanded on in Section 2 of this Guide. For this study we use the Net Present Value method with a Required Rate of Return of 15% and an equipment lifetime of 10 years.

When we calculate the total cost of the described options we obtain the results listed in Table 1 in which the cost of losses before mitigation is normalised to 100.

The remaining PQ costs of variant 'A' can be explained by the three faults in the transmission network (Figure 2). The remaining PQ costs of the variants 'B' to 'E' are the costs of the non-protected CF and heat set process.

	Solution	Interruption cost (%)	Mitigation cost [1]	Total cost
now	Current situation	100	0	100
A	Restructuring	26	62	88
B	UPS on complete BCF (1,625 kVA)	60	303	363
C	UPS on parts of BCF (670 kVA)	60	152	212
D	DySC on complete BCF (1,625 kVA)	60	109	169
E	DySC on parts of BCF (670 kVA)	60	87	147

Table 1 - Comparison of the different mitigation options (cost before mitigation is 100%)

[1] *These costs include maintenance and standby costs, being 5% of the purchase price annually in the case of a UPS and 1% for a DySC*

Figure 7 shows that only the option in which the network is restructured is economically attractive with the economic criterion used.

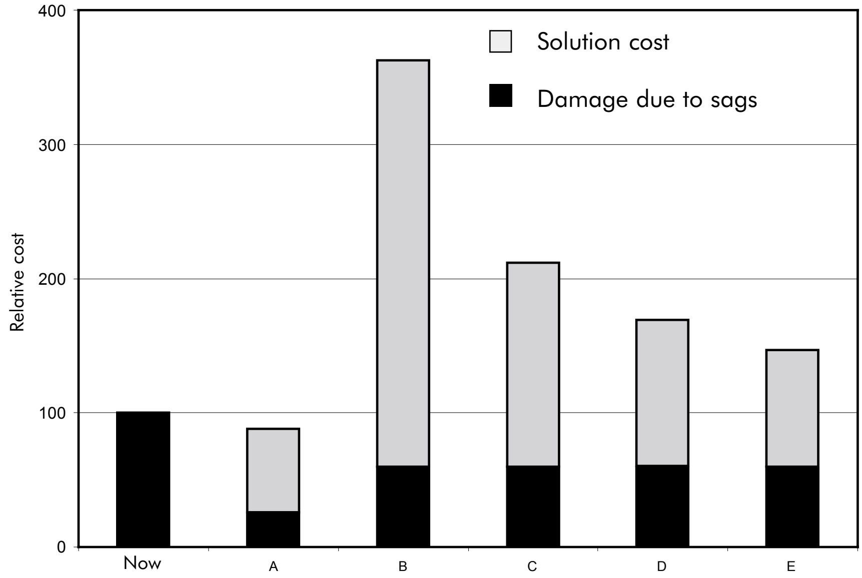

Figure 7 - Total costs for different options for a Belgian textile extrusion process

Costs expressed in % of base case 'now'. See Table 1 for definitions of A-E.

Although some companies consider a project horizon of 10 years for such an investment as being very long, this company decided to make the investment. They argued that some indirect or hidden costs, which are very hard to estimate, are not taken into account in this calculation. Such costs include, for example, discontent of the workforce due to breakdowns caused by the sags and quicker ageing of machines.

To illustrate that the outcome of a voltage sag case study depends highly on the location, Figure 8 shows a case study in a plastic extrusion plant performed by Electrotek Concepts [2]. In this case study, where the annual process interruptions were near 15, no network restructuring was possible. In this case, protecting the machine controls and winders turned out to be the cheapest option.

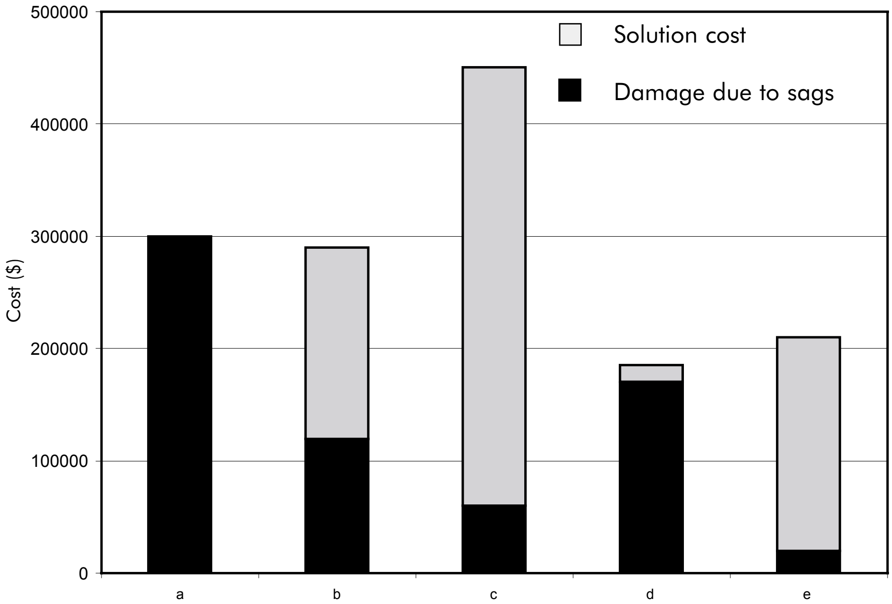

Figure 8 - Total costs for different options in Electrotek case study [2]

a) Base case - no change
b) Primary static switch
c) Service entrance energy storage (2 MVA)
d) Protect machine controls and winders
e) Combined static switch with controls protection

Conclusion

Based on the case study of a Belgian textile plant, this section provides guidelines on how to perform a voltage sag case study. Information has to be collected on the production process, its immunity against sags, the financial loss due to a process interruption and data on the annual number of sags. If this information is gathered, possibilities to reduce outage costs can be investigated. These possibilities can be classified into three groups:

- within the process itself
- between the process and the grid
- within the grid.

Immunisation between the process and the grid can be applied in every situation, whereas immunisation possibilities within the process or within the grid have to be studied separately in each case.

In our case study it turned out that immunisation options within the process were not possible. Immunisation options between the process and the grid appeared to be too expensive and a restructuring of the network was the only financially viable option. A different case study of a plastic extrusion process, performed by Electrotek Concepts, showed the protection of the controls and winders being the most cost-effective solution.

From the above case studies, and the subsequent discussion with extrusion machine manufacturers, we could draw a few additional interesting conclusions:

- Standard products from the extrusion machine manufacturers have hardly any sag immunity beyond the legally binding regulations
- Retrofitting textile extrusion lines after their installation is sometimes possible. Therefore, we recommend users of textile extrusion machines to contact their electricity supplier and/or the network operator about the number and characteristics of sags over the past few years. Based on this information they can install machines with the required immunity to voltage sags instead of buying ones having little or no sag tolerance.

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KATHOLIEKE UNIVERSITEIT
LEUVEN

University of Leuven, Energy Institute
Celestijnenlaan 300a
3001 Heverlee
Belgium

Tel: 00 32 16 32 25 08
Fax: 00 32 16 32 29 85
Email marcel.didden@mech.kuleuven.ac.be
Web: www.kuleuven.ac.be

Copper Development Association

Copper Development Association
5 Grovelands Business Centre
Boundary Way
Hemel Hempstead HP2 7TE
United Kingdom

Tel: 00 44 1442 275700
Fax: 00 44 1442 275716
Email: helpline@copperdev.co.uk
Websites: www.cda.org.uk and www.brass.org

COPPER

European Copper Institute
168 Avenue de Tervueren
B-1150 Brussels
Belgium

Tel: 00 32 2 777 70 70
Fax: 00 32 2 777 70 79
Email: eci@eurocopper.org
Website: www.eurocopper.org