REDUCED PQ-RELATED COSTS FOR THE SWEDISH PULP & PAPER INDUSTRY

Mats HÄGER
STRI – Sweden
mats.hager@stri.se

Åke CEDER
Vattenfall Sveanät – Sweden
ake.ceder@vattenfall.com

Erik THUNBERG
Svenska Kraftnät – Sweden
erik.thunberg@svk.se

INTRODUCTION

This paper summarizes some of the experiences and conclusions from a joint project, named Elvis, between STRI (research institute), Elforsk (research association for utilities) and SSG (trade association for Pulp & Paper industries). The main objective was to present suitable actions to reduce power quality (PQ) related costs for the Swedish Pulp & Paper (P&P) industries.

The PQ-related costs for the Swedish P&P industries were identified in a pre-study performed by STRI and SSG in 1998. The annual costs are in the range of 9-25 million Euro, mainly related to malfunctions in variable speed drives due to voltage dips caused by lightning faults on transmission lines.

The Elvis project

The Elvis project was jointly financed by Elforsk and SSG. The work started in August 2001 and ended in December 2002. The project group was set up by members from STRI, Elforsk, SSG, several utilities and P&P industries, as well as one observer from the Swedish Energy Agency (a total of 18 members). The mix of persons engaged in the project proved to be very successful, and formed a natural forum for a wide and constructive dialog.

The project was divided into two parts, the first dedicated to power quality audits and collecting fault and disturbance statistics from three selected typical case studies. The second part focused on common questions and general problems, as well as dedicated studies and solutions for each case.

Together with the project meetings some of the related work topics were covered by invited specialists giving short presentations and opportunities for detailed discussions.

Case studies

Three cases have been studied, each case consisting of one P&P-industry and the supplying utility. The selection of cases was based on different network configurations as well as different kinds of production in the industries. The case locations in the transmission network are shown in Fig 1.

![Fig 1: Case locations in the transmission network (red=400kV, green=220 kV)]

<table>
<thead>
<tr>
<th>Industry</th>
<th>Products</th>
<th>Utility</th>
<th>Voltage levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCA Ortviken</td>
<td>Fine-paper</td>
<td>Sydkraft</td>
<td>130 kV</td>
</tr>
<tr>
<td>Holmen Hallstävik</td>
<td>News-paper</td>
<td>Vattenfall</td>
<td>(220/70 kV)</td>
</tr>
<tr>
<td>Billerud Gruvön</td>
<td>Mixed prod.</td>
<td>Fortum</td>
<td>(130/33 kV)</td>
</tr>
</tbody>
</table>

Power Quality Audits

In the first part of the project PQ-audits were performed at all the selected industries and utilities. Disturbance data and fault statistics were collected, and the following topics were stated for discussion:

Industries:
- Disturbance data, measurement data
- Disturbed equipment and economical consequences
- Distribution system configurations
- Information from utilities
- Relay protections – types and selectivity
- Insulation coordination
- Equipment immunity requirements - procurement
- Improvements already performed

Utilities:
- Network configurations
- Network impedance
- Information to customers
- Geographical locations
- Fault statistics, disturbance recordings
- Cause of faults (lightning, birds etc)
- Line-configurations, towers, insulation, grounding
- Voltage regulation limits, nominal levels
- Disturbing loads – disturbed load/customers
- Overlaying network emission
- Protection systems – Auto-reclosing
- Improvements already performed
Disturbance and fault statistics

In order to determine a cause and effect relation, disturbance data from the industries were correlated with the fault statistics from the utilities. One major problem related to this work was that the resolution in data i.e. reliable time tagging and detailed descriptions of disturbances and faults were missing in many cases.

Result of PQ-audits

Several proposals for the following work could be formulated based on the PQ-audits. It was then decided to focus on both common and general questions as well as dedicated studies of network and industries in each case.

GENERAL QUESTIONS

Disturbance Costs for P&P-industries

The main objective for the Elvis-project was to find methods and solutions in order to increase the availability of the production. The economical consequences (i.e. losses due to unplanned production stops) establish the base for investments in different solutions in order to improve availability and reduce the number of unplanned production interruptions.

Two fundamental questions were formulated relating to the following:

1. How much does an unplanned production stop actually cost in terms of lost production, quality degradation etc?
2. How is this cost calculated considering different investments, products and production volume?

All three participating P&P industries provided calculations of their costs related to unplanned production interruptions. Two basic kind of disturbances were recognized:

- Minor disturbance
- Major disturbance

A minor disturbance is characterized by a short duration of a few hour, the absence of wrecked equipment and a smooth restart procedure of the production. A major disturbance normally lasts more than 4-5 hours, often accompanied by equipment failures and additional problems not directly caused by the primary fault. For an unplanned interruption, costs relating to the following main groups were identified:

- Loss of production
- Quality degradation
- Equipment breakdown

Loss of production-costs is based on the calculated contribution margin per hour for each production unit. For each of the three cases studied, the total costs for a severe disturbance (24 hour shutdown) can reach between 0.5–1 million Euro.

Costs related to the main groups above are relatively easy to calculate, but the contribution of the following 'soft factors' is more difficult to calculate and price:

- Information from network operators
- Goodwill
- Delayed deliveries
- Raw-material waste
- Loss of internal energy production

The first question asked by the operators after a disturbance is if the cause is generated internally within the mill, or has an external cause. Consequently, information about transmission network events that may have disturbed the production at a sensitive large industry should be forwarded to the operators in charge of such industries as soon as possible.

Variable speed drives immunity

Discussions with three large manufacturers of variable speed drives have resulted in several proposals for increased immunity against voltage dips. Today all three manufacturers can provide systems based on new technologies and voltage source converters. These systems have a much better immunity compared to many older systems. The question regarding improved immunity is still important since the majority of systems in operation are of older types.

The IEC product standard for variable speed drives, IEC 61800-3 [1] (formerly IEC 147), mainly covers limits for stationary voltage variations, and does not provide detailed immunity requirements for voltage dips. In the IEC standard, different performance criteria are defined, and for voltage dips, it is recommended that the drives are shut down without automatic recovery.

The actual behaviour of a variable speed drive is not only determined by the product standard, but also how internal protections such as dc under-voltage protection pick-up level, delays etc are chosen during engineering and commissioning. From a process operational point of view, optimal settings of protections and control functions are not always achieved.

During the discussions it became clear that several actions could be considered in order to improve immunity and ride-through capability of variable speed drives. Unlike sectional drives, single drives can often be automatically restarted after a trip due to a short under-voltage, minimizing the risk for a cascaded total shutdown.
Other possible improvements discussed with the manufacturers were the following:

- Lower level on the under-voltage protection, even removal of the under-voltage protection may in some cases be considered (to avoid unwanted trips)
- Increased input ac supply voltage to rectifier bridges
- Blocking of regeneration control to the ac network during normal operation (prevents thyristor breakdown during regeneration)
- Charging of dc capacitors using motor inertia
- Status of dc capacitors (energy storage degradation due to ageing)

Before these actions are taken, the manufacturer should be consulted.

**Coordination of measurements**

The quality of the collected fault information and disturbance data from the three selected sites varied and in some cases only limited information was available.

In order to track the chain from the initiating line fault down to the consequences in the industries, reliable data are essential. Synchronised recordings of the events, with a time uncertainty less than a few minutes, in the network and in the industries, are therefore often required.

An important parameter that needs to be uniformly defined is the true change in voltage magnitude during a fault. Registrations of voltage dips are event-triggered recordings, starting when the voltage level falls below a defined threshold. The threshold is normally chosen as a percentage of a nominal level, for example 90% of Un. If measurements are performed at different voltage levels, the actual pre-fault voltage level may differ from the nominal level. Many instruments do not record the pre-fault/dip voltage, and therefore information on the full voltage variation is lost.

A document for coordination of measurements performed by utilities in their networks and in the industries has been compiled. The document covers, in addition to the above mentioned items, also instrument connections, fault type logging, logging of relay-protection actions, auto-reclosing logging, disturbance logging etc.

**CASE STUDIES**

**SCA Ortviken - Sydkraft**

Since the fault statistics and disturbance data from this case did not indicate any specific 'weak point', and the fact that equipment within the factory seemed to be sensitive to rather low voltage reductions, the work was focused on the internal distribution system.

One common question related to equipment sensitive to voltage changes is how voltage dips originating from faults in the power system propagate and change their characteristics in the internal distributions system. A following question is then what kind of conclusions regarding equipment immunity that can be drawn based on voltage measurements performed in locations far away from the disturbed equipment.

**Extended measurements**

Four PQ instruments (Dranetz pp1 equipped with PQ-Plus task cards) were installed at different locations within the mill. The internal clocks were manually synchronised and in order to capture events simultaneously the trigger levels were correlated and set rather close to the expected nominal level at each location. Due to a rather low lightning intensity in the area in 2002, only four events related to external faults were captured during the measuring period (May-October).

**Voltage dip propagation**

The severity of a voltage dip is often expressed as the lowest remaining voltage and duration. During registration of voltage dips the obtained dip characteristics are only valid for the measuring point.

Measurements and evaluation based on rms-measurements may not fully cover the characteristics required for a study of voltage dip propagation. If the instruments are capable of storing instantaneous voltage values, evaluation using symmetrical components (i.e. positive sequence voltage drop, negative sequence voltage etc) will add further possibilities to a relevant determination of dip characteristics and propagation [2] [3].

The voltage dip propagation from the power line fault to the load terminals inside the mill depends on several factors.

- Type of fault
- System grounding
- Transformer winding connection and vector group
- Amount and types of loads connected
- Internal power generation

The simultaneous rms voltage variations in the supplying 130kV level and a local 6 kV distribution system, during a three-phase fault in the supplying 130kV network, are shown in Fig 2 and Fig 3.
Fig 2: Voltage dip (rms-volts) captured at 130kV voltage level during a three-phase fault (incoming supply)

The pre-fault voltage level in Fig 2 is 66V, and the voltage drop 20.5V, corresponding to a relative voltage drop of 31%.

Fig 3: Voltage dip captured in the internal 6kV distribution system during the same event as in Fig 2

The pre-fault voltage level in Fig 3 is 60.5V, and the voltage drop 14.7V, corresponding to a relative voltage drop of 24%.

As shown in Fig 2 and Fig 3 the voltage reduction during a remote three-phase fault can be considerably lower in the internal 6kV system compared to the incoming 130kV. One factor contributing to the reduction is the transient load influence from many synchronous and asynchronous motors.

Gruvön – Fortum

Based on the fault statistics received for this case, both the network configuration and the effects using a current limiter were studied. The total number of faults (single-phase and multiphase faults) in power lines close to Gruvön are shown in Fig 4.

Almost 50% of all disturbances experienced by Gruvön are caused by faults in these lines. It is therefore relevant to study alternative network configurations and tools to limit the effects due to faults in lines D-H.

Network configuration

The 130kV station supplying Gruvön is Orrby, located approximately 3-4 km from Gruvön, see Fig 5. Orrby consists of two busbars A (main) and C (auxiliary). A possible change in configuration is to connect line H and the tapping of line B, to the C- busbar. Gruvön will then be supplied by line A (via busbar A) only. The definite effects from such change have not been studied, however it is clear that the voltage reductions at Gruvön due to faults in lines D-H will be reduced. This change was discussed with Fortum and Gruvön, and the utility will consider costs and consequences to implement the proposal during 2003.
Fault current limiter

Another possible method to limit the number of severe voltage dips at Gruvön is to install a current limiter at Orrby in series with line H. Since around 50% of the disturbances encountered at Gruvön are due to line faults on this, and other succeeding lines, a reduction of the fault current will be beneficial. These lines act like a large distributed 'antenna' and many voltage dips due to faults on these lines propagate to Orrby and Gruvön.

In Fig 6, the principal layout of the studied current limiter is shown. The inductance L and capacitance C are chosen to form a low impedance series resonant circuit at 50 Hz. During a fault, the increase in current through the series circuit will raise the voltage across the capacitor to a pre-determined level, set by the surge arrester MOV. When the surge arrester is 'active', the series impedance of the circuit will increase and the fault current is limited. The design is simple and reliable, it does not include any control functions or auxiliary power supply.

The design and theory of the current limiter is further described in [4].

Simulations

Simulations were performed with the network model shown in Fig 4. The current limiter parameters were chosen to correspond to the actual conditions at Gruvön, Un=130kV, In=500A, Sk=1000MVA.

During a three-phase fault on line H located 1 km from Orrby, the voltage drop with the current limiter installed is around 15% from the pre-fault level.

The reduced fault current obtained by the current limiter will also influence the fault current levels experienced by the relay protections. Coordination of protection settings, and eventually changed protection schemes, is therefore required.

The total cost of a current limiter, as the one studied, depends on several local factors: space available within the substation, available equipment, selection of protection equipment etc. In this case, the cost is around 1 million Euro.

Hallstavik - Vattenfall

The evaluation of fault- and disturbance statistics from Vattenfall and Hallstavik showed that line faults originating from both the 70kV- and the 220kV systems cause disturbances at the mill. It was then decided to study various actions on the power lines to reduce the number of line faults and/or change the characteristics of the voltage dips.

Flash density

The majority of the line faults are due to lightning, either direct hits or backflashover. Selective information on the local lightning density and current magnitude are therefore important parameters when statistical calculations of fault frequencies are performed on individual lines.

The average flash density (flashes/km² and year) in the Hallstavik area during 13 years is shown in Fig 7.

No areas with an exceptional flash density can be identified, the average density is between 0,1 – 0,5 flashes/km² and year.

Fig 7: Average flash density close to the 220 kV and 70 kV lines in the Hallstavik area (1987-2000)
(provided by Ångströmlaboratoriet, Uppsala, Sweden)
The landscape around Hallstavik is rather flat and located close to the coastline, which probably contributes to a low and rather uniform flash density.

**Line faults**

Two basic approaches can be considered for actions on power lines:

1. Reduction of the number of line faults
2. Change of fault characteristics

**Line-arresters**

The most efficient method to reduce the number of line-faults is to apply line arresters in each tower of the power line. These will prevent the excessive voltages due to lightnings normally leading to a flashover and short circuit. Theoretically, all line faults due to lightning can be eliminated with line arresters. A practical implementation of line arresters must be studied in detail, since additional mechanical stress is applied on the towers and the grounding impedance requirement is changed. In this case, several long lines are involved and the cost for implementing line arrester will be high.

The work performed included a compiled overview on surge arrester techniques, applications and international case studies.

**Sky-wires - Grounding**

From the fault statistics for the 70kV system during 1997-2001, the number of different fault types and the number of faults causing a disturbance at Hallstavik are shown in Fig 8.

![Fig 8: Number of disturbances caused by phase-phase and phase-ground faults in the 70kV system around Hallstavik.](image)

In Sweden, the 70kV systems are impedance grounded and consist mainly of wooden poles and cross arms not connected to ground. The majority of line faults, as shown in Fig 8, are phase-phase faults, which are more severe for the industry since they create a large voltage drop and propagate through transformers. A phase-ground fault in an impedance grounded system will not create a large voltage drop and only have a minor effect in the mill.

The effect of cross arm grounding has been studied. The phase-ground insulation level will then be reduced and the percentages of phase-ground faults are likely to increase, reducing the number of disturbances in Hallstavik. The results show a significant reduction of phase-phase faults, around 50%, if the tower and cross arm grounding impedance is around 10 ohms.

**CONCLUSIONS**

The Elvis project formed a new kind of forum for a constructive dialog between utilities, equipment manufacturers and industries. Studies performed within the project provided results for several possible and cost effective actions to be taken by utilities, manufacturers and industries.

One main outcome of the project is an increasing understanding that many power quality related problems are a concern of many parties involved, and that an efficient way to solve these problems is based upon a mutual dialog.

**References**


