INCREASING RELIABILITY OF SUPPLY FOR THE PULP AND PAPER INDUSTRY; A CASE STUDY FROM FORTUM DISTRIBUTION AND BILLERUD-GRUVÖN

Jörgen HASSELSTRÖM
Fortum Distribution AB– Sweden
jorgen.hasselstrom@fortum.com

Eskil AGNEHOLM
Fortum Distribution AB– Sweden
eskil.agneholm@fortum.com

Per IVERMARK
Billerud-Gruvön AB - Sweden
per.ivermark@billerud.com

ABSTRACT

In this paper the joint activities of Fortum Distribution AB and Billerud-Gruvön to reduce the consequences of lightning related power quality issues at Billerud-Gruvön is described. In a previous CIRED 2003 conference paper some potential solutions to reduce the sensitivity to lightning was analyzed. It is the purpose of this paper to describe how Fortum and Billerud since 2004 have worked to identify which solutions that should be used. Most of the decided actions has been implemented and have been in operation during the last lightning season. This enables an initial analysis of the effectiveness of the techniques. Among other technical solutions, the paper describes the design of a new 130 kV transmission line designed to provide unsurpassed performance to lightning induced interruptions. The line includes double shield wires and line arresters on all three phases on each pole-pair for the entire distance of the line.

INTRODUCTION

In contrast to some other energy intensive industries the paper and pulp (P&P) industry is very sensitive to short interruptions and voltage sags. This is mainly due to malfunction of certain variable speed drives. The main source for short interruptions is lightning, affecting the transmission lines located in the vicinity of the pulp and paper mills.

The economical consequences due to power-quality (PQ) problems for the P&P industries are very high. Investigations for the Swedish P&P industry have shown that annual costs are in the range 9 - 25 M€ [1]. To reduce the sensitivity to longer interruption most P&P industries have full contingency support. A failure on a power transformer or on an incoming transmission line does not lead to any longer interruption of power for the industry. However, the industry will experience a short interruption or a voltage sag with a duration mainly set by the properties of the relay protection system. The most common cause for voltage sags are not permanent failure on the system but rather lightning induced temporary faults on the transmission line system.

Billerud-Gruvön is a paper mill well known for its innovation. Today the mill has three pulp lines, six paper machines, a coating machine and two flash dryers for drying market pulp. Gruvön produces sack and kraft paper, fluting and white liner for containerboard, and market pulp. The paper mill is relatively resistant towards voltage sags with a rms voltage level exceeding 0.8. At around 0.8 the duration of the sag must not exceed 400 msec in order not to cause a production interruption. Voltage dips with lower magnitude requires shorter trip times but should to the largest extent be avoided if possible. A drop in voltage, or a short interruption, leading to a production stop is estimated to cost Billerud-Gruvön between 0.5 to 1.5 M€.

Discussion on how to improve the ability to withstand lightning induced failures on transmission lines has been on-going for decades; see for example Ref. [2]. It is not the purpose of this paper to describe and discuss the usefulness of all these methods in detail. Rather, the paper focuses on Fortum Distribution and Billerud-Gruvön's joint efforts to improve reliability at the paper mill. In a previous 2003 CIRED conference paper three case studies, each consisting of one pulp and paper industry and one utility was presented [1]. Fortum Distribution and Billerud-Gruvön was one of the case studies. In the paper, various solutions to reduce the sensitivity to lightning were mentioned. Some of the suggested solutions have been implemented combined with some others solutions not described previously.

In recent years, investments at Billerud-Gruvön have led to increasing load demands. Actions were needed to strengthen the network both on the 30 kV side and on the feeding 130 kV lines. As the network was reinforced the goal was to at the same time make the busbar at Orrby (feeding Gruvön) more resistant towards voltage sags and short interruptions. The paper describes among other things the design of a 130 kV transmission line between Orrby and a national grid substation (denoted Station A) that has been rebuilt in order to provide unsurpassed performance to lightning induced interruption. The line includes double shield wires and line arresters on all three phases in each pole-pair. The line may be viewed as state-of-the-art and represents top-level transmission line reliability for energy intensive customers who are extremely sensitive to short interruptions and voltage sags.

LIGHTNING ACTIVITY AND FLASH DENSITY

The isokeraunic map is used to indicate the relative frequency of lightning on a geographical basis. On an international level, Sweden has relatively low thunderstorm days, see Fig. 1. As a comparison, parts of Southeastern US experience more than 100 thunderstorm days per year and central Europe average between 20 and 60 thunderstorm days per year.

It can be seen that the Southwestern part of Sweden is most sensitive to lightning. In the region where Billerud-Gruvön is located, indicated by an arrow in Fig. 1, one expects between 12-14 thunderstorm days each year. The lightning season in this part of Sweden extends from May to September.

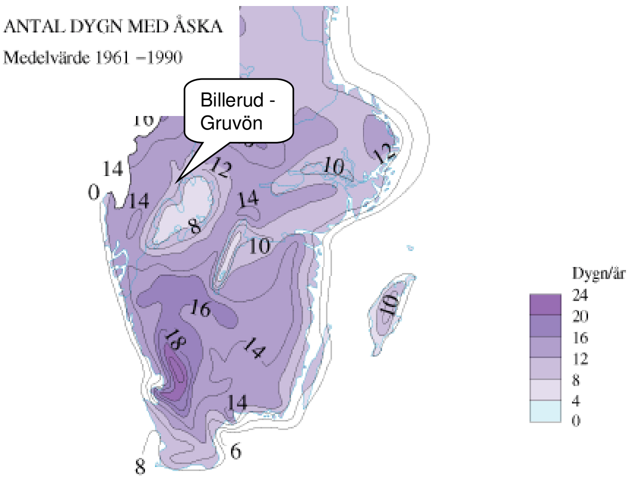

Fig. 1. Average thunderstorm days in southern part of Sweden. The location of Billerud-Gruvön is indicated by the arrow. Data from Ref [3].

Of equal importance to thunderstorm days is the overall flash density in the area. This information is given in Fig. 2. Billerud-Gruvön is located in the area indicated to experience between 20 and 50 ground flashes per 100 km^2.

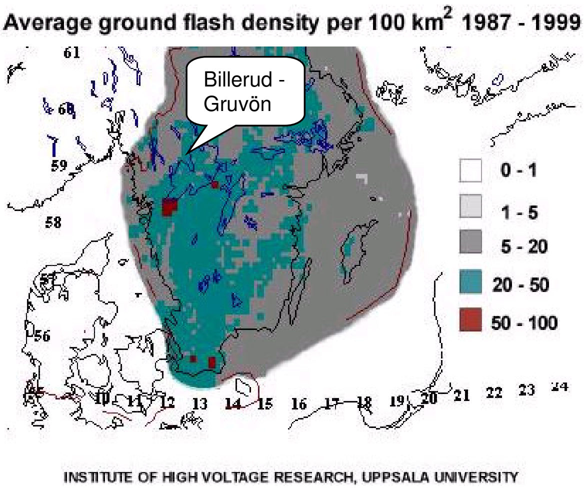

Fig. 2. Average ground flash density per 100 km^2 in southern part of Sweden. The location of Billerud-Gruvön is indicated by the arrow. Data from Ref [4].

Lightning affects power systems either through direct strikes or through indirect strokes. Direct strokes cause a flashover that causes a short circuit on the system. To protect against this type of strokes several extreme measures needs to be taken. Even these measures may prove to be ineffective. Indirect strokes may through a magnetic field with high rate-of-charge induce a voltage in nearlying conductors. This may in turn lead to a flashover and short-circuit on the power line. This type of flashovers is more common on distribution lines; protection against them is still difficult but certainly easier than for direct strokes.

HISTORICAL PERFORMANCE

Prior to 2006, Billerud-Gruvön was fed from Orrby substation by three parallel 30 kV overhead lines. The distance from Orrby to Billerud-Gruvön is only a few kilometers. Orrby substation consisted of two 130 kV busbars, A (main) and C (auxiliary) and was supplied from nearlying Station A and Glava substation by three 130 kV lines, two of them (of which one is only a tap) are connected to the same busbar at Station A and one is connected to Glava, see Fig. 3.

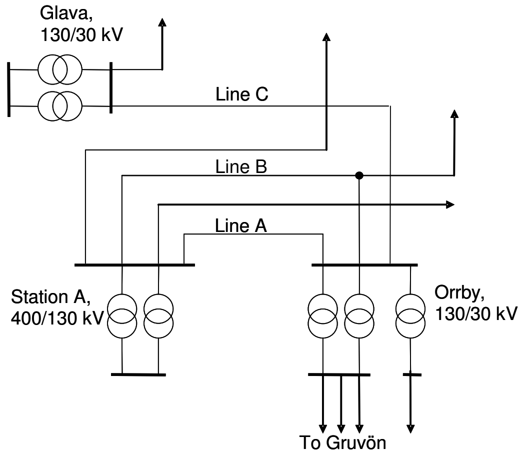

Fig. 3. Simplified one-line diagram depicting the 130 kV network around Billerud-Gruvön in 2005.

By means of calculations, a very high reliability towards longer interruptions can be verified for the P&P mill. However, the spatial extension of the 130 kV network in the vicinity of Orrby makes the substation sensitive to lightning induced voltage sags. Historically, between 1 and 2 outages has been observed on each of the transmission lines feeding Orrby and on those in the vicinity to Orrby and Station A. The majority of these failures are reclosing operations indicative of lightning induced breaker trips. Billerud-Gruvön has historically experienced about 5-6 voltage sags per year with a rms voltage magnitude below 0.8. In the 80-90 % voltage range approximately 20 sags are observed on an average year.

ACTIONS TO IMPROVE RELIABILITY

System Configuration

In 2006, the 30 kV lines from Orrby to the P&P mill was replaced by two 130 kV cables. In addition to a capacity upgrade, this reduces the sensitivity towards weather related outages on the line segment between Orrby and Billerud-Gruvön. Modification were also done at Orrby substation in order to ensure that Billerud-Gruvön will be supplied from a separate busbar of the feeding substation Orrby (now consisting of two 130 kV main busbars, A, B and one auxiliary, C, see Fig. 4. This was one of the proposed actions analyzed in Ref [1].

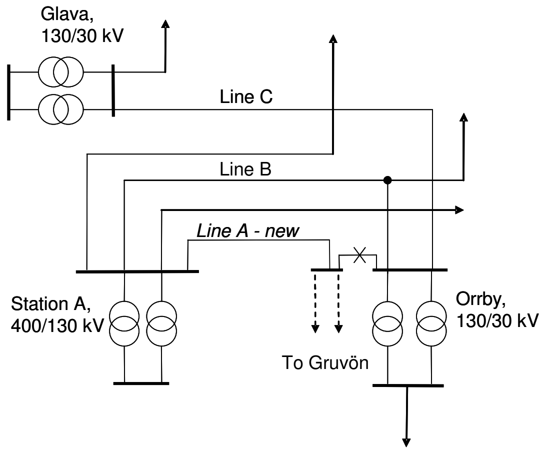

Fig. 4. Simplified one-line diagram depicting the 130 kV network around Billerud-Gruvön at present date.

The simplified design leads to fewer switching operations, both during normal and fault conditions at the busbar in Orrby. It also reduces the total number of expected voltage sags and the severity of the voltage dips as seen by Billerud-Gruvön.

Transmission line upgrade

The 130 kV transmission line between Orrby and Station A has been rebuilt and upgraded in order to increase the capacity of the line and to provide unsurpassed performance to lightning induced interruptions. The line now includes arresters on each phase (and pole-pair), bird protection on the cross-arm over each phase, and double shield wires, see Fig. 5. Due to the increase in conductor diameter also new poles were needed. This line configuration has not been used by Fortum Distribution or in the Nordic countries previously. It may be viewed as state-of-the-art and represents top-level transmission line reliability for energy intensive customers who are extremely sensitive to short interruptions and voltage variations.

The polymer-line arresters were supplied from Tridelta. They are of Metal Oxide Varistor (MOV), (MCOV = 108 kV) with an operating voltage of 86 kV. The creepage distance is 3485 mm and the height of the arrester is about 1.3 m. Nominal discharge current is 10 kA and Temporary Over Voltage (TOV) is 124 kV and 118 kV for 1 sec and 10 sec duration, respectively. The arresters are grounded together with the shield-wires at each pole-pairs, with the exception of a few pole-pairs where the conditions where such that it is difficult/impossible to obtain low resistance.

Fig. 5. A picture of the new 130 kV transmission line between Orrby and Station A.

With a large quantity of line arresters on a power line it is important to be able to identify faulty components. This is achieved by a disconnector at the bottom of each line-arrester. Upon malfunction of the line-arrester, the ground-wire is disconnected making it easy to observe during normal inspection.

The transmission line polymer composite insulators are from Pfisterer-SEFAG (system voltage: 145 kV). The lightning impulse voltage is 570 kV and the one-minute power frequency withstand voltage (wet) is 240 kV. The creepage distance is 2900 mm.

To present date the experiences from the new design is positive. It may be argued that having arresters mounted on each phase on every pole-pair is somewhat unnecessary, especially in combination with double shield wires, and that equal performance may be obtained using simpler solutions. Also, Billerud-Gruvön will still be affected by faults occurring on lines supplied from the same busbar in Station A. However, it is clear that the new line will generate very few lightning-induced breaker trips. As time goes by the general experiences from the line will become clearer and conclusions may be drawn whether to continue working with a similar design or a simplified one.

Protection system

Modifications were done on the relay protection system to ensure that operational times are as low as possible. The old protection system consisted of distance protection of electro-mechanical type. The duration of the voltage sags are very important to the process industries; it is favorable to keep the trip time as low as possible, especially for high-magnitude voltage sags, and trip times below 500 msec are usually an absolute requirement. For this purpose, state-of-the art communicative relays were installed from Station A to the nearlying substations. This enables trip time below 100 msec for the entire distance of the transmission lines and not only about 50 % of the lines that is normally the case using standard technology and zone setup (zone one is set to about 75 % of the total length of the line). With the old protection system the breaker time was at least 400 msec for a zone 2 failure.

Upgrades were also done on the line Station A-Orrby; distance protection relay of modern type were installed at Station A. At present date, no communication is used between the substations. Special care has been taken in order not to obtain selectivity problems between the 130 kV cables and 130 kV busbar at Orrby and the new overhead line.

COMPARISONS OF PERFORMANCE

The new system has been in operation during one lightning season, 2006. It is thus somewhat early to draw any major conclusions on the effectiveness of the investments. When analyzing the lightning induced interruptions a positive trend is observed. It can be seen that the duration of the voltage sags has been reduced; very few voltage sags with duration exceeding 400 msec was observed in 2006. Also the total number of voltage sags was reduced and the new transmission line experienced no outage or reclosing operation in 2006 due to lightning. One should nevertheless bear in mind that 2006 was from a lightning perspective a relatively fortunate year. As time goes, more certain conclusion may be drawn on the overall effectiveness of the chosen actions.

FUTURE ACTIVITIES

In this section some of the additional activities that have been discussed in order to further increase the reliability of supply to Billerud-Gruvön will be described. In the earlier CIRED conference paper [1] the idea of installing a current limiter at Orrby in series with the line from Glava was discussed. Simulations were performed and it was estimated that the voltage drop could be reduced by 15 % from the pre-fault level. However, due to the other activities in and around Orrby in 2006 the use of a fault current limiter at Orrby is no longer an option. Current limiters may be evaluated at Station A substation if the situation remains unsatisfactory after the already performed (and planned future) activities have been evaluated.

What is scheduled are further upgrades of the relay protection equipment in Orrby to ensure communication between Orrby and Station A. In addition, an upgrade of the parallel 130 kV line from Station A to Orrby via a tap is planned to obtain similar resistivity towards lightning as the newly built transmission line. In combination with necessary relay upgrades, this will ensure consistent function of the tap line and secure a reliable back-up to the newly built power line.

CONCLUSIONS

In this paper the joint activities of Fortum Distribution AB and Billerud-Gruvön to reduce the consequences of lightning related power quality issues at Billerud-Gruvön is described. A series of different methods to improve reliability at the mill has been evaluated, both on a technical and economical basis. A new type of transmission line has been built in order to provide unsurpassed performance to lightning induced interruption. The line includes double shield wires and line arresters on all three phases in each pole-pair. In addition, modifications have been done both on a overall system and substation level as well as on the relay protection system. The system has been in operation during one lightning season (2006). Although this year was a relative fortunate year in terms of lightning, the initial analysis indicates significant improvements in power quality for the new system. A brief discussion on some upcoming activities in and around Billerud-Gruvön is also presented in the paper.

ACKNOWLEDGEMENT

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