VOLTAGE DIPS AT LKAB IN SWEDEN. ANALYSIS OF DIP- AND OUTAGE STATISTICS, MITIGATION OPTIONS AND ECONOMICAL EFFECTS.

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ABSTRACT

This paper presents results of a study performed in order to determine the origin and consequences of voltage dips at LKAB and to bring forward an action plan for elimination of the problem. The results of the study indicate that there is a big compatibility gap between power quality requirements of standard industrial equipment and the power quality that the power utility provides. This gap results in significant loss of LKAB's revenue. It has also been concluded that available technical solutions are economically justified despite high investment costs. In order to obtain an optimal solution, improvements of both the feeding network and the load have to be implemented.

INTRODUCTION

LKAB is a word-wide supplier of iron ore products located in the North of Sweden – Kiruna, Malmberget and Svappavaara. The production process consists of several stages such as mining, hoisting, enrichment and production of pellet. The production has a high degree of automatization with hundreds of drives controlled by power electronics - tyristor rectifiers and frequency converters. One of the problems that affect the outcome of LKABs activities are production discontinuances caused by voltage dips in the electrical system. For this reason, a study has been performed with the aim to analyze the origin and consequences of the voltage dips and to bring forward an action plan for elimination of the problem.

WHAT ARE VOLTAGE DIPS AND WHY ARE THEY SO TROUBLESOME?

Voltage dip is defined as voltage drop by more than 10% of the nominal voltage with a duration of 10 ms - 90 s. Voltage dips are resulting from short-circuit and earth faults in transmission and distribution systems due to lightning over-voltages, components failures or mechanical failures caused by severe weather conditions.
Different electrical equipments have different immunity for voltage dips. Least sensitive are resistive loads such as ohmic heaters and incandescent lamps. Other equipment, such as IT equipment, home and office electronics, rectifiers and frequency converters require a continuous power supply and trip when the voltage drops below a certain level. The effects of voltage dips on service continuity depend on frequency of occurrence, amplitude, duration and type of failure.

ELECTRICAL SYSTEM IN THE MINE DISTRICT

The schematics of the electrical system in the mine district in the north Sweden is shown in figure 1 below.

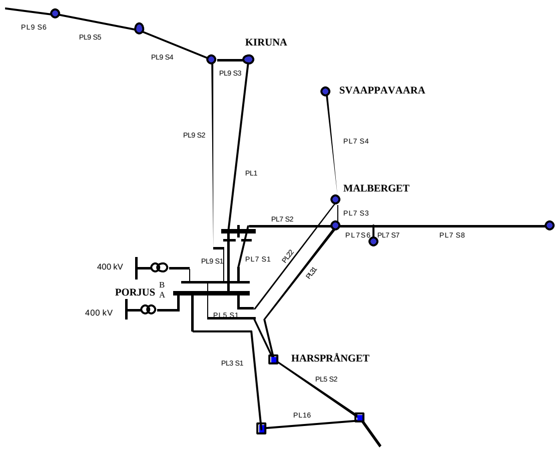

Figure 1. Electrical system in mine district.

The system is clearly defined and relatively easy to analyze. The power generation is located in Porjus and Harsprånget and the production facilities are located in Kiruna, Svappavaara, and Malmberget. The power to the Kiruna plant is transmitted through two 130 kV lines PL1 and PL9 on a distance of approx 150 km and the power to the Malmberget plant is supplied through three 130 kV lines PL31, PL22 and PL7S2. The supply to Svappavaara is coming from Malmberget by the 130 kV line PL7S4.

DISTURBANCE RECORDS

During the period 2002-2005 disturbances have been recorded independently by LKAB and by the power utility Vattenfall. LKAB has recorded voltage dips on the 130 kV PCCs in Kiruna and Malmberget by means of event recorders and kept a logbook on power quality related outages - their duration and economical effects. Vattenfall kept a logbook on all disturbances in transmission lines that caused operation of the protection relays showing the instant of occurrence and location of the failure. By analyzing the available information, conclusions could be drawn regarding immunity levels, origin of the outages and their consequences.

Immunity levels in LKAB and consequences of voltage dips

Figures 2 and 3 show all voltage dips registered in Kiruna and Malmberget sorted by their consequences.

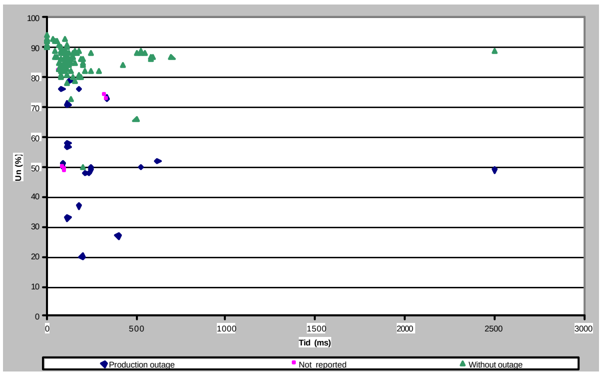

Figure 2. Voltage dips recorded in Kiruna 2002-2005 sorted by consequences.

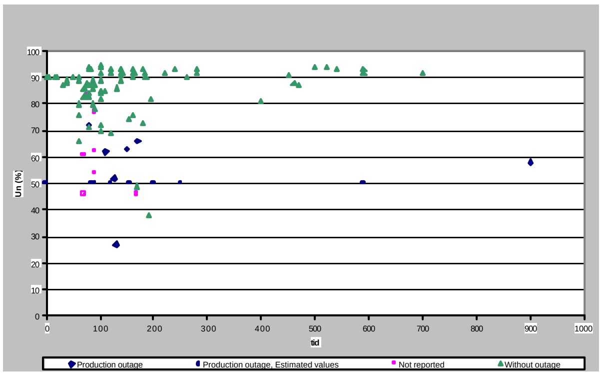

Figure 3. Voltage dips recorded in Malmberget 2002-2005 sorted by consequences.

During the period 2002-2005, 146 voltage dips have been recorded in Kiruna and 117 in Malmberget. Out of that number, 21 dips have caused production outage in Kiruna, 16 in Malmberget and 14 in Svappavaara.
It can be seen that the immunity level in Kiruna is ca. 0,8Un and in Malmberget ca. 0,7Un. Majority of the outages however is due to voltage dips that are below 0,5Un which is far below the immunity levels.
The economical effects of the voltage dips have been calculated using actual loss of finished product for each production outage. The results are summarized in table 1 below where the average number of production outages and average loss of revenue per annum for each plant is presented.

Plant	Number of outages p.a.	Loss of revenue p.a. kEUR
Kiruna	5,25	470
Malmberget	4	800
Svappavaara	3,5	640
Total	**12,75**	**1 910**

Table 1. Loss of revenue per annum.

The figures in table 1 do not include costs of additional outage time caused by voltage dip related component failures. That makes, that the estimations of pay-off time presented in this report are quite conservative.

Origin of voltage dips at LKAB

Figures 4 and 5 show all voltage dips in Kiruna and Malmberget sorted by their origin.

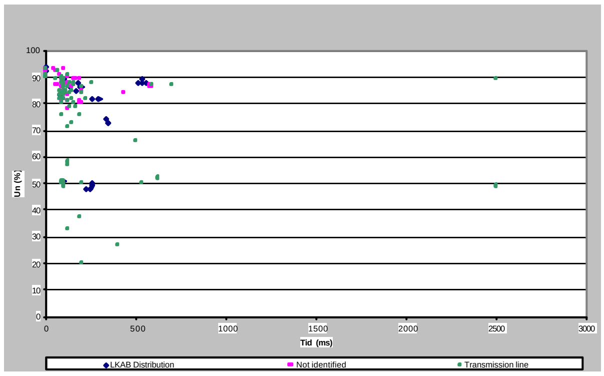

Figure 4. Voltage dips recorded in Kiruna 2002-2005 sorted by origin.

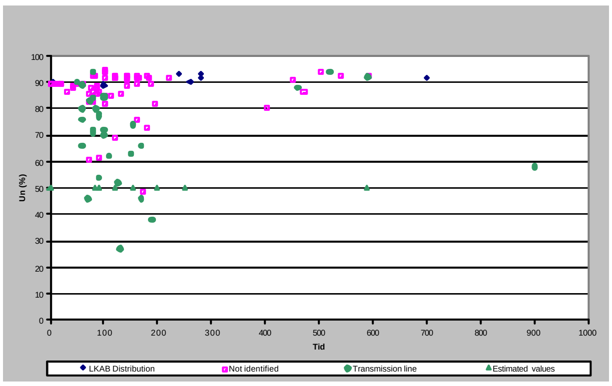

Figure 5. Voltage dips recorded in Malmberget 2002-2005 sorted by origin.

Although the origin of all voltage dips that have been registered by the event recorders is not known, due to the

fact that they didn't cause any protection operations, it can be concluded that the most severe dips were caused by failures in the 130 kV transmission system. In the worst case, the voltage dropped to 20% of the nominal voltage.
By analyzing the reports from Vattenfall together with the recordings made by LKAB, one could find out the location of the failures that have caused outage in the LKAB's production units. Figure 6 shows location of failures that have caused voltage dips lower than 0,8Un in Kiruna and Malmberget.

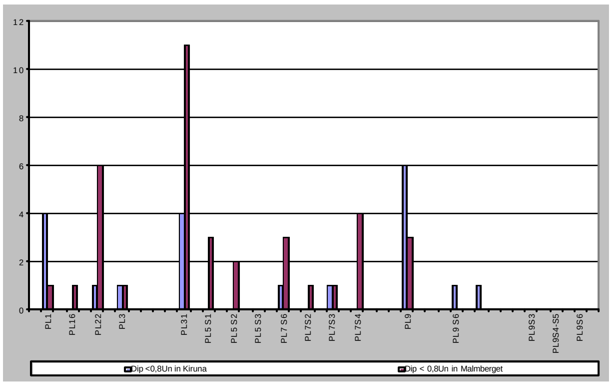

Figure 6. Number of failures per line that have caused voltage dips < 0,8 Un in Kiruna and Malmberget.

It can be concluded that service interruptions in Kiruna are mainly caused by failures in lines Pl1, Pl9 and PL31 while service interruptions in Malmberget are mainly caused by failures in lines PL31, PL22 and PL7S6.

Conclusions

The analysis of the disturbance statistics show that there is at present a large gap between the power quality required by the equipment in order to ascertain an interruption free operation (Immunity level) and the power quality provided by the power utility. This gap is illustrated in figure 7.

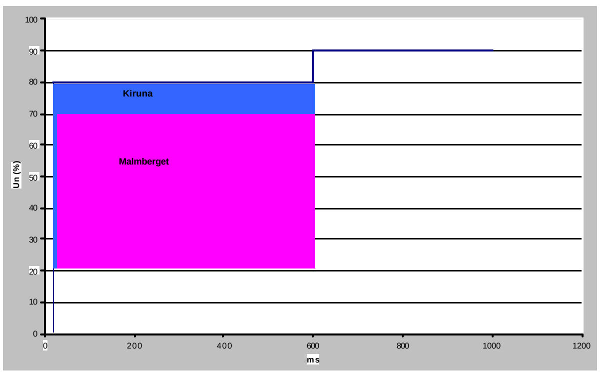

Figure 7. Power quality gap.

Figure 7 shows that the gap between the immunity level of the equipment and the power quality that the Utility provides is at present 50-60% of the nominal voltage. In order to reduce the number of outages in production and thus reduce the loss of income, big efforts have to be done on both the power supply side (Vattenfall) and the load side (LKAB).

EVALUATION OF MEASURES TO REDUCE THE POWER QUALITY GAP

The factors that affect service reliability are on one side, the severity of the voltage dips, i.e. frequency of occurrence, amplitude, duration and type of failure and on the other side the immunity of the equipment. The following measures have been considered:

Reduction of frequency of occurrence
The number of failures can be reduced by improving the withstand capability of the network to lightning surges. This can be obtained by:

- Improved insulation
- Line arresters

Reduction of amplitude of voltage dips
The amplitude of voltage dips depends on the impedance ratio between different sections of the feeding system. This can be positively affected by:

- Reinforcement of the system with parallel lines
- Installing current limiters in the system

Reduction of duration
The duration of a voltage dip depends on how fast the short-circuited line will be disconnected. The total clearing time depends on the protection setting and on the operation time of protective relays and of the circuit breakers. Replacement of older protection relays and older circuit breakers with modern ones will reduce the duration of voltage dips.

Type of failure
Analysis of the failure reports show that many of the failures are of multiple phase type and that quite often a failure occurs in two or three lines simultaneously. Such failures are especially troublesome as they result in high amplitude and long duration of the voltage dip and are affecting the whole system. Possible measures for this type of failures are:

- Physical separation of the lines
- Improved grounding
- Line arresters

Improvement of immunity level for critical loads
The risk for service interruption can be minimized by using equipment with higher immunity for voltage dips.
Since the majority of the critical loads consist of variable speed drives, possible improvements of immunity levels for VSDs have been investigated. It has been concluded, that a

realistic immunity level is 0,65Un. This level can be achieved by:

- Retrofit- or replacement of older drives
- Installing of UPS systems for all control and auxiliary voltage
- Utilizing drive-through capabilities wherever possible
- Control and adjustment of protection setting
- Control and adjustment of operating voltage on all bus bars

Mitigation equipment in the distribution network
Installing voltage dip mitigation equipment such as UPS or DVR within LKAB network can stabilize the voltage on the bus bars fed through these devices and in such way minimize the risk of production outages.

Economical evaluation of different measures

The summary of economical evaluation of some of the measures discussed in the previous section is presented in tables 2 and 3.

	Measure	Loss reduction p.a. (kEUR)	Cost of investment (kEUR)	Pay-off (years)
1	Line arresters in PL31	590	830	1,41
2	Line arresters in PL22	260	970	3,73
3	Line arresters in PL1	155	1 390	8,97
4	Line arresters in PL9	310	1 390	4,48
5	Line arresters in PL7S6	260	830	3,19
6	CL in PL31	590	1 550	2,63
7	CL in PL1 and PL9	155	2 780	17,94
8	CL in PL1 and PL9	310	2 780	8,97

Table 2. Economical effects of investments in transmission lines.

The results presented in Table 2 show that investments in lines PL31, PL22 and PL7S6 feeding Malmberget and Svappavaara give the best return. Improvements of lines PL1 and PL9 feeding Kiruna are more expensive and give lower return on investment due to larger length of the lines and higher current rating.

The results presented in Table 3 show that investments in higher immunity of equipment give short pay-off time but have limited effect on the outage time since the majority of the voltage dips causing production outages are below 0,65Un and can not be prevented by these improvements. Investments in mitigation equipment type DVR and UPS show very long pay-off time and have also limited effect on the total outage time.

	Measure	Loss reduction p.a. (kEUR)	Cost of investment (kEUR)	Pay-off (years)
1	Mitigation devices in one sub-station	145	1 330	9,17
2	Immunity improvement of all critical loads	500	1 360	2,72

Table 3. Economical effects of investments in immunity improvement and in mitigation devices.

Conclusions

The economical analyze shows that investments in increased immunity and improvement of 130 kV lines show good profitability and will pay-off in relatively short time. Figure 8 shows estimated investment costs, reduction of lost revenue and return on investment accumulated for a period of 10 years. It can be concluded that the estimated return on investment in 10 years is 10 MEUR for investments in the transmission lines and 3,6 MEUR for investments in increased immunity of equipment.

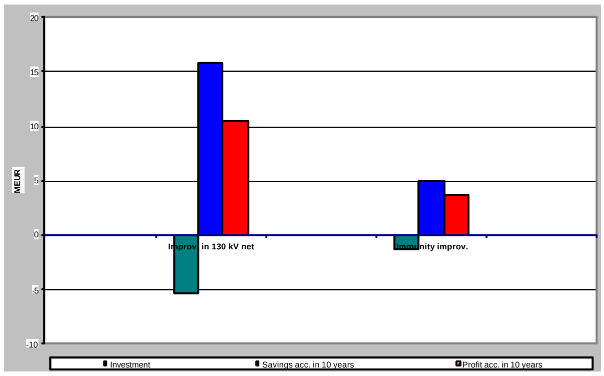

Figure 8. Profitability of investments.

SUMMARY

The results of the study show that there is a big compatibility gap between power quality requirements of standard industrial equipment and the power quality that the power utility provides. This gap results in significant loss of the industrial company's revenue. It has also been concluded that there are technical solutions available that can improve the voltage dip statistics of the transmission line and improve the immunity of the equipment or of the local network against voltage dips. The economical evaluation shows that some of these methods, despite high investment costs, are economically justified and profitable. In order to find out the best solution, characteristics of both the feeding network and the load have to be analyzed. Our study has shown that in the case of LKAB, investments in improvement of the transmission system in combination with investments in improvement of immunity of electrical loads are most effective and profitable. Based of these results, a close cooperation between Vattenfall and LKAB has been started in order to successively implement the recommended improvements and to follow up the results. The goal of the first step is to improve the immunity of equipment to 0,65Un and limit the voltage dips to 0,5Un/150ms and thus reduce the quality gap from today's 50-60% of the nominal voltage to 15% year 2008.

Figure 9. Power quality gap - goal for year 2008.