

DYNAMIC VAR COMPENSATION OF MINE HOISTS FOR IMPROVEMENT OF POWER QUALITY AND INCREASE OF PRODUCTIVITY AT LKAB SWEDEN.

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ABSTRACT

The hoisting system in the iron ore mine at LKAB in Kiruna is a fast changing load that affects power quality of the electrical system. In order to reduce the voltage variations and harmonic distortion to acceptable levels and at the same time increase production capacity it has been decided to install a static var compensator (SVC). The selection of ratings and configuration of the SVC has been based on a system study consisting of load- and power quality measurements as well as harmonic- and load-flow simulations. As a result of the study a SVC consisting of fixed harmonic filters and thyristor controlled reactor (TCR) has been selected.

The results of simulations demonstrate that the selected SVC will reduce the voltage variations on the feeding 6 kV bus bar from 20% to less than 3% and at the 145 kV PCC from 6% to less than 2%. The total harmonic distortion will be reduced to less than 4,8% at the 6 kV bus bar and less than 1,5% at the 145 kV PCC. Thanks to the SVC, the production capacity of the hoisting system will increase by approx. 30%.

INTRODUCTION

The mine hoisting system at LKAB Kiruna consists of an upper and lower system. The upper system consists of 7 hoists each rated 4,3 kW, 6,3 kV connected to a common 6,3 bus bar. The lower system consists of 4 mine hoists each rated 5,4 MW, driven by converter controlled AC motors and will be completed with a 5th hoist to year 2012.

The upper hoists are driven by thyristor controlled DC motors and represent a fast varying load affecting the whole supply system. The duration of a load cycle is approximately 90 s. and consists of acceleration phase, operation at full speed and retardation. During that time the load is changing between 0 and 9 MVA causing voltage variation on the feeding 6,3 kV bus bar and on the 145 kV PCC.

According to the contract with the network operator, the frequent voltage variations at the 145 kV PCC should not exceed 3%. This level is already exceeded when one hoist is accelerating and five hoists are running at full speed. The planned extension of production capacity from 25 to 35 Mt per year will require further restrictions of start- and operation sequences, which mean that the capacity of the hoist system can not be fully utilized.

In order to reduce the voltage variations and harmonic distortion to acceptable levels and thus increase the production capacity it has been decided to install a static var compensator (SVC)

DEVELOPMENT OF TENDER SPECIFICATION

The development of the tender specification has been preceded by a thorough system study that consisted of measurements and systems simulations.

Measurements

The measurements have been performed with one hoist in operation and all existing harmonic filters disconnected as well as with all hoists in normal operation and the existing filters switched on. During the measurements, the active power, reactive power, fundamental- and harmonic voltages and currents have been recorded. The measurements with one hoist in operation have been performed partly by recording the operation cycle with 1,25 kHz resolution, partly by using standard network analyzer with 10 sec. storage intervals and recording the average, minimum and maximum values within the storage intervals.

The results of the power, voltage and harmonic measurements are presented in figures 1-2.

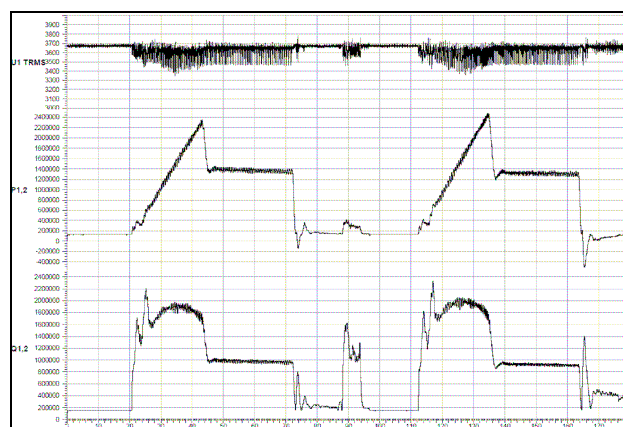


Figure 1. Power, and voltage measurements with 1,25 kHz resolution

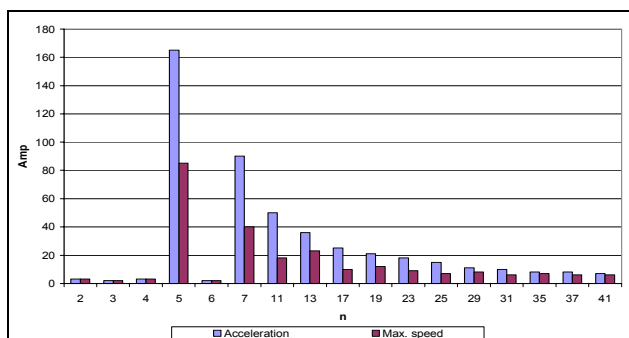


Figure 2. Harmonic currents

Analysis of results of the measurements lead to the following conclusions:

- Voltage variation on the 6,3 kV busbar caused by one hoist is 3,6%.
- Max harmonic distortion on the 6,3 kV busbar caused by one hoist is 6,3 % which means that suitable harmonic filters are required in order to reduce the harmonic distortion to acceptable level when several hoists are in operation.
- The power consumption is 7,2 MW/6,9Mvar during the acceleration phase and 4,2 MW/3 Mvar during operation at full speed.
- The duration of the acceleration phase is approx. 24 sec., operation at full speed 27 sec., retardation and unloading 21 sec.

It can be concluded that the load variations are to fast and to frequent to be compensated by conventional breaker switched filters but are realistic for a static var system (SVC)

Selection of compensator’s rated output and configuration.

In order to select the rated output of the compensator, load-flow simulations have been performed for the following cases:

Case	No. of hoists in acceleration	Number of hoists at full speed
1	1	6
2	2	5
3	3	4
4	4	3
5	5	2

Table 1. Operation cases

For each case, two alternatives have been investigated

- A. With compensator required to reduce the voltage variations on the 6 kV busbar to 3%.
- B. With compensator required to reduce the voltage variations on the 6 kV busbar to 5%.

The summary of the calculations’ results is presented in table 2.

Case	Q comp Mvar	dU 145 %	dU6 %
1A	24,83	1,71	2,99
1B	19,99	1,98	4,87
2A	28,96	1,63	2,99
2B	23,98	2,07	4,87
3A	33,14	1,98	2,99
3B	28,03	2,17	4,87
4A	37,4	2,15	2,99
4B	32,12	2,28	4,87
5A	41,75	2,32	2,99
5B	36,26	2,38	4,87

Where:

Qcomp = compensator output

dU145 = voltage variation on the 145 kV bus bar

dU6 = voltage variation on the 6 kV bus bar

Table 2. Summary of the system simulations

Based on the results of simulations and taking into consideration the load capacity of the step down transformer, it has been concluded that a realistic scenario is the one corresponding to Case 3 which means 3 hoist accelerating and 4 hoists operating at maximum speed with a limitation of voltage variations at the 6 kV busbar to 3%. Consequently, a SVC with compensation range between 0 and -35 Mvar has been selected. In order to allow operation condition corresponding to Case 4 that will still meet voltage variations requirement on the 145 kV busbar, the SVC shall be designed to fulfill harmonic distortion requirements according to table 3 when 4 hoists accelerate simultaneously and 3 hoists operate at maximum speed.

Performance parameter	Guaranteed value at PCC	Guaranteed value at 6,3 kV bus bar
Total voltage distortion	1,5%	4,8%
Individual voltage harmonics, odd	1,0%	<60% of Compatibility levels as per EN 50160
Individual voltage harmonics, even	0,2%	<60% of Compatibility levels as per EN 50160
Total current distortion	5%	5%
Individual current distortion, odd	3%	3%

Table 3. Harmonic distortion requirements

SELECTED SVC SOLUTION

The offered SVC solution is based on thyristor controlled reactors with 3 filter banks and a regulating range of 0 – 35 Mvar capacitive. The thyristor valves as well as the control system for the SVC will be delivered mounted in a prefabricated container building. Even the cooling system with water-to-air heat exchanger is mounted in the container building. The heating tower with the fans is mounted in direct connection to it. The filter banks with the circuit breakers are outdoor design. As LKAB's mine is north of the Arctic Circle, special focus was given to clearance distances for all outdoor equipment, especially regarding iron dust and snow height. Also the high variation of outdoor temperatures was an important design factor as the air conditioning system of the container building needed to be designed for -40degrees C up to +40 degrees C.

The basis for the SVC design can be summarized in following main design considerations:

- Selection of the SVC size and filter size and the tuning of the selected filters
- Selection of the control strategies to meet the performance requirements
- Simulations of the expected performance

Compensator configuration

The mine hoist drives are typical 6-pulse converters, with symmetrical load pattern and with characteristic harmonics of 5th, 7th, 11th, 13th, etc.. To define the right filter size and tuning for the SVC system, computer simulations were used. As input data for the simulations the measured harmonic generation of the mine hoist system, the expected harmonic generation of the TCR (characteristic frequencies are fixed at 5th, 7th, 11th, 13th,...) and information about the impedances of the supply network were used. Also the cable connection between the feeding switchgear and the SVC system with the filters was important, as the inductance of the cable had to be considered. The selected SVC configuration with filters for the 5th, 7th and the 12th order is shown in the single line diagram (Fig.3). All filters are damped to avoid the risk of resonance. The 5th and 7th tone filter damping is realized using Q-rings on the filter reactors as damping devices. The 12th tone filter is designed as a high-pass filter so that a damping of the 11th, 13th as well as higher tones can be achieved.

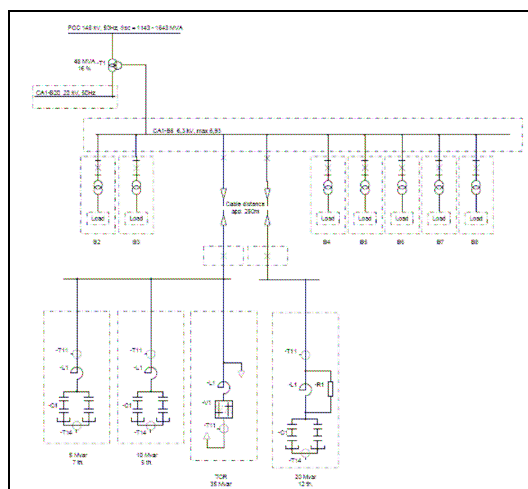


Figure 3. SVC, single-line diagram

Main characteristics

The major goal of the SVC system is to provide the dynamical and continuous control of the reactive power depending on the reactive power required by the hoist systems. This is done by phase-angle control of the current through the TCR (thyristor controlled reactor). The current amplitude set is done once per half cycle. The harmonic filters perform the dual task of providing reactive power generation for the hoists at fundamental frequency and performing the harmonic filtering needed to take care of various harmonics generated by the hoists and the TCR. The balance of the fixed reactive power generation of the filters and the variable reactive power absorption of the TCR makes up the reactive power output of the SVC system at every instant (Fig.4).

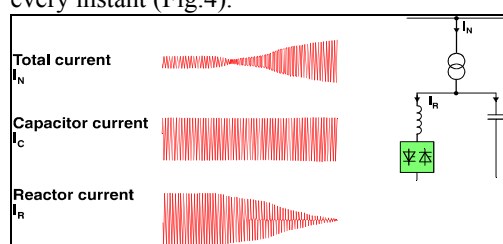


Figure 4. Reactive power generation of the SVC

Expected performance

The expected performance of the SVC is first of all depending on the SVC rating in relation to the max. reactive power requirements from the hoists, as well as how the available reactive power is used by the control strategy and the applied algorithms.

Performance guarantees for flicker reduction, max. voltage variation on the 6kV bus (caused by the mine hoists), minimum power factor (reactive power control), as well as for harmonic distortion (as per Table 3) were given for the case that 3 mine hoist are in acceleration mode and 4 mine hoists are in max. speed mode. This mode is called "performance mode" as all guarantees were given on this mode.

Voltage variations

As per the previous studies the reactive power requirements with 3 % voltage variations on the 6,3 kV bus is for the performance mode 33 Mvar. That means that the SVC of 35 Mvar control range is in line with this requirement. Additional to that 2 Mvar can be used for further voltage variation reduction, if there are no flicker reduction requirements. As the open loop reactive power regulation (flicker regulation) is a very quick acting algorithm we recommend to reserve the 2 Mvar so that flicker reduction is possible. The closed loop regulation for power factor regulation, Mvar regulation or voltage regulation on the 6,3 kV bus is a comparatively slow acting algorithm.

Harmonic distortion

The major harmonic currents generated by 6-pulse converters and for the TCR (thyristor controlled reactor) are mainly 5:th, 7:th, 11:th and 13:th order. Harmonics that are multiples of the 3rd order need to be considered, because of variations in the feeding network or component tolerances. This may have a minor impact for the performance of the SVC, but has to be considered as design criteria.

The calculated harmonic voltage distortion values for the 6-pulse converters and the TCR in total as shown in Fig.5. were used in our simulation for the expected harmonic distortion.

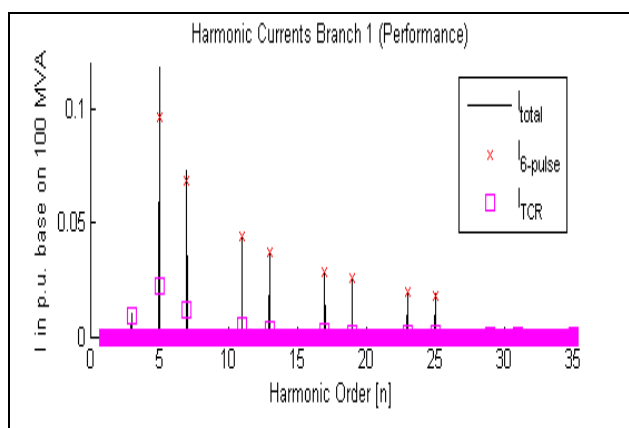


Figure.5. Harmonic current for 6-pulse and TCR

The following figure is showing the expected voltage distortion at PCC, which is below the guaranteed 1.5% THD values.

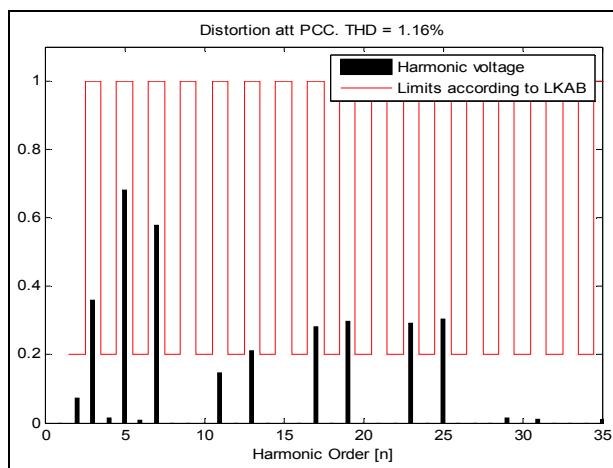


Figure 6. Expected voltage distortion on the 145 kV busbar

INCREASE OF PRODUCTIVITY

The efficiency of the hoisting system has a great impact on the production capacity of the Kiruna plant. At present, in order to limit voltage variations on the 145 kV bus bar to 3%, a 24 sec. time delay between unloading and next start must be applied resulting in an operation cycle of 96 sec. Since the capacity of each hoist is approximately 40 tons per lift, the total extrusion capacity is at present 10 360 tons per hour (7 hoists x 40 tons x 37 cycles/hour). The new SVC will allow simultaneous acceleration of 3 hoists which will eliminate the need of the start delay and thus reduce the operation cycle to 72 sec resulting in hoisting capacity of 14 000 tons per hour. It can be concluded that installation of the SVC result in an increase of the capacity of the hoisting system by approx. 30 %.

SUMMARY

Dynamic compensation of the mine hoists by means of a Static Var Compensator will bring significant benefits to LKAB in terms of reduced voltage fluctuations, reduced harmonic distortion and increased productivity. Thanks to these improvements, LKAB will be able to meet the new production goals without risk of power quality related service disturbances and without exceeding compatibility limits defined by the network operator.