FACTS FOR VOLTAGE STABILITY AND POWER QUALITY IMPROVEMENT IN MINING

Rolf GRÜNBAUM
ABB AB – Sweden
rolf.grunbaum@se.abb.com

Niklas WILLEMSEN
ABB AB - Sweden
niklas.willemsen@se.abb.com

ABSTRACT

Feeding safe and reliable power to mining can be a challenge, with loads depending on secure, high quality power supply. A traditional way to deal with shortcomings in power transmission and distribution is reinforcing the grid by building new lines, or upgrading voltages to higher levels. Such measures, however, are expensive and time-consuming, if, indeed, they are permitted at all. A more cost as well as time effective way is introducing FACTS, thereby utilizing existing facilities more efficiently. The paper highlights SVC (Static Var Compensator), a member of the FACTS family, for improving power supply to mining industry. Benefits and salient design features are presented, as well as examples of successful SVC installations in the mining industry in the world.

INTRODUCTION

Feeding safe and reliable power to mining complexes can be a challenging task. Loads such as mine hoists, mining shovels, crushers, pumps, conveyor belts etc are sensitive to fluctuations in the feeding voltage, thereby depending on secure, high quality power supply. At the same time, availability and reliability demands are high (production outages very expensive).

Mining complexes are often forced to operate in environments characterized by one or several of the following factors:

-Remote areas where power supplies are weak or inadequate

-Rough, inaccessible terrain, more or less unsuited for OH line construction

-Elevated or high isokeraunic activity

The picture is further complicated by modern industrial drives, harming the power quality of feeding grids, unless proper mitigating measures are taken [1].

A traditional way to deal with shortcomings in power supply is reinforcing the grid by building new lines, upgrading voltages to higher levels, or building local power plants to supply parts or the total of the load. Such measures, however, are expensive and time-consuming, if, indeed, they are permitted at all. A more cost effective way may be to introduce FACTS, thereby utilizing existing facilities more efficiently.

FACTS

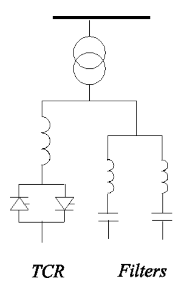
The term “FACTS” (Flexible AC Transmission Systems) covers a family of power electronic systems utilized in AC power transmission and distribution [2]. FACTS solutions are particularly justifiable in applications requiring rapid dynamic response, ability for frequent variations in output, and/or smoothly adjustable output. Under such conditions, FACTS is a highly useful option for improving the utilization of transmission and distribution grids.

With SVC (Static Var Compensator), a member of the FACTS family, stability and power quality are maintained in grids dominated by heavy and complex industrial loads such as large mining complexes.

SVC

An SVC is based on thyristor controlled reactors (TCR), thyristor switched capacitors (TSC), and/or harmonic filters. Two common design types, each having its specific merits, are shown in Fig. 1a and 1b.

A TCR consists of a fixed shunt reactor in series with a bi-directional thyristor valve. A TSC consists of a capacitor bank in series with a bi-directional thyristor valve and a damping reactor which also serves to de-tune the circuit to avoid parallel resonance with the network. The thyristor switch acts to connect or disconnect the capacitor bank for an integral number of half-cycles of the applied voltage.



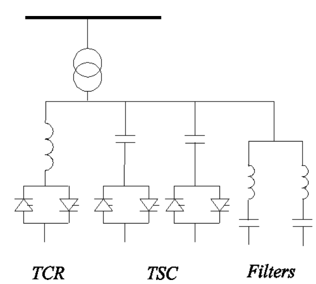


Fig. 1a. TCR/filter configuration. Fig. 1b. TCR/TSC/filter configuration.

The TSC is not phase angle controlled, which means it does not generate any harmonic distortion.

A complete SVC based on TCR, TSC and harmonic filters may be designed in a variety of ways, to satisfy a number of criteria and requirements in its operation in the grid. In addition, slow vars by means of Mechanically Switched

Capacitors (MSC) can be incorporated in the schemes, as well, if required.

The control of the SVC requires a fast acting and accurate control system to be able to counteract rapid changes in the bus voltage and control the TCR phase angle to the desired value. This is done by a micro-processor based and highly flexible system that measures all necessary voltages and currents in the SVC, and determines the susceptance needed by the SVC. The output of reactive power is usually based on a positive sequence measurement of the three phase voltages at the Point of Common Coupling (PCC). For special under-voltage and over-voltage strategies, individual phase voltages are measured.
In some cases, where voltage unbalance is an issue and the loads are sensitive to unbalance, the SVC can be equipped with negative sequence control to individually regulate each phase of the TCR valves [3].

STEADY STATE VOLTAGE CONTROL

Let us assume a generic case as shown in Fig. 2. The load centre is fed through a transmission line and the load consists to a large extent of induction machines which are sensitive to under-voltage. In this case both active and reactive power to the load have to be supported through the transmission line. Apart from the ohmic losses this will generate in the system it will also show up as challenges at faults in the system.

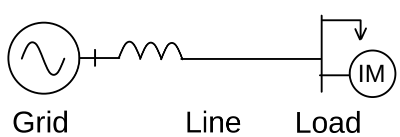


Fig 2 Single line diagram of generic system

A common way of representing the load conditions in a system is by a so called nose curve [4]. The nose curve gives the relation between voltage drop and the amount of power that is drawn from the busbar, in our case this will be the busbar at the mine. An example of this type of curve is given in Fig 3.

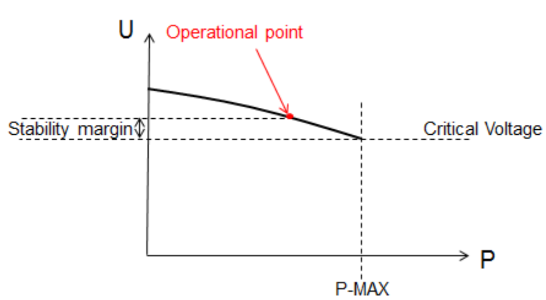


Fig 3 Nose curve without SVC

As can be seen in Fig 3, as the mine starts to consume power the voltage on the busbar will start to drop. This drop is primarily caused by the reactive power consumption of the loads. The current load condition at the mine is defined as the operational point on the nose curve. As the mine starts to consume more and more power the operational point will move to the right and the voltage drop will increase. Every system has a critical voltage where a further drop will make the system instable and collapse, and consequently a value for the maximum amount of power (P-max) that can be consumed during stable conditions as seen in Fig 3.

The same system as in Fig 3 is presented in Fig 4 but with the scenario with an SVC.

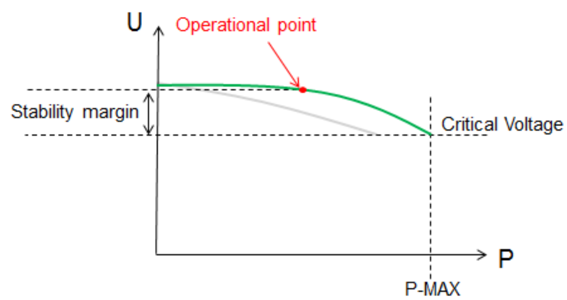


Fig 4 Nose curve with SVC

As can be seen an SVC can compensate for the voltage drop caused by the reactive portion of the load. This will act as a stabilizing force in the system and give advantages in terms of:

- Increased stability margin
- Higher voltage for the loads at the operational point
- Allow more power to be transmitted to the mine

DYNAMIC VOLTAGE CONTROL

Under-voltage control at faults and overvoltage control during light or no load conditions are key features for SVC operation. Under-voltage situations can occur at generator outages, starts of large induction machines or faults in adjacent feeders. The faults will typically be temporary, cleared after 100-150 msec. During the fault, the voltage will go down to a higher or lower degree. Under-voltage situations are especially difficult when the load consists of a large percentage of asynchronous machines, a common situation in mines. During the fault the asynchronous machines will slow down in speed, affecting the system when the fault is cleared. In the worst condition the grid may not be able to reach voltage recovery after this kind of fault. However, this can be remedied through the use of SVC for dynamic reactive power support during the fault [3]. The generic single line diagram after installation of the SVC is shown in Fig. 5.

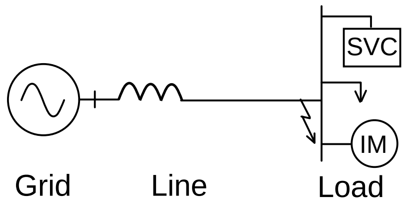


Fig 5 SVC installed at a load centre

Other types of loads such as DC drives for mine hoists are voltage sensitive, as well, and may require dynamic voltage support for various load conditions.

TWO RECENT CASES

Mining complex in Australia

A large iron ore mining complex in Western Australia is fed over a more than 500 km radial 220 kV grid with generation at one end and the mining load plus additional generation at the other. The main part of the generation is located at the coast, whereas the main load is inland.
The 220 kV line connecting the load with the coastal generation area suffers degraded availability due to outages caused by lightning.
The load is to 85% heavy mining loads with crushers, conveyors, pumps, etc. The remainder chiefly consists of air conditioning. The fault level at the 220 kV PCC is low, dipping below 200 MVA in certain grid situations. During contingencies, the feeding voltage could drop to 0.8-0.5 p.u., tripping relays, and losing large motors as well as other vital functions.
To improve the power supply, as well as accommodate planned increases of ore extraction, an SVC has been installed at the 220 kV mining substation. The primary function of the SVC is to provide reliable reactive power support to the area and stabilise the 220 kV voltage under steady-state conditions as well as transient disturbances, keeping the system and loads online.
The SVC (Fig. 6) is rated at 75 Mvar inductive to 75 Mvar capacitive (±75 Mvar), with an overload capability of ±100 Mvar for a duration of up to one hour. The SVC also controls two MSCs, each rated 220 kV, 25 Mvar, and located in the same substation.

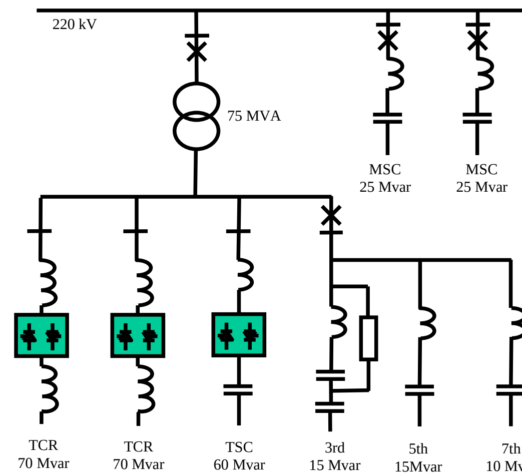


Fig. 6. 220 kV SVC plus MSC.

Experience from the initial test period shows excellent correlation between load drops which would have led to voltage rises, and the SVC going inductive to keep the feeding grid voltage at its set point. Likewise between load increases which would have led to voltage drops, and the SVC going capacitive to support the voltage. The system voltage before, during and after the SVC has been switched in is presented in Fig 7 below. The SVC is switched in around 4 PM and the sysem voltage is lowered just before in order to contain any over voltages in the energization cycle.

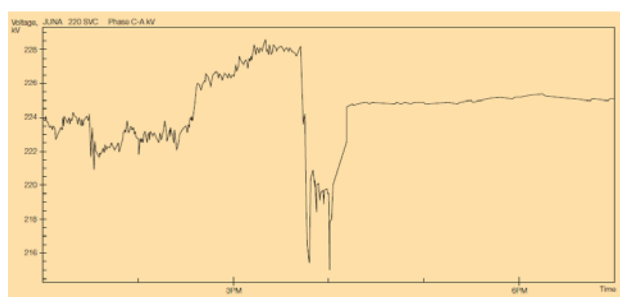


Fig 7 Voltage before and after connection of SVC

Iron ore mine in Sweden

In 2009, an SVC was commissioned in the LKAB iron ore mine at Kirunavaara in the north of Sweden. The SVC, rated at 0-35 Mvar capacitive at 6.3 kV, has the purpose of improving power quality at the 145 kV PCC as well as inside the mine by reducing voltage fluctuations and harmonics. As a direct benefit, with the SVC in operation, the ore hoisting capacity has risen, as well, making the extracting process more efficient than before [5,6].

Mine loads

In the underground mine of LKAB, iron ore is brought to the surface by a total of seven mine hoists, each driven by a

4.3 MW thyristor equipped 6-pulse DC drive and representing a fast varying load affecting the whole supply system. The load cycle consists of three different phases: acceleration, full speed operation and retardation. A typical load cycle duration is about 90 sec.
Before the advent of the SVC, due to insufficient strength of the feeding grid, simultaneous operation of the drives was seriously restricted, preventing the full capacity of the hoists to be utilized. Only 3% of voltage variations are permitted at the 145 kV PCC. Thus, to limit the voltage variations at the PCC to an acceptable level, only one mine hoist could be started at a time, resulting in reduced productivity. With a planned extension of production capacity from 25 Mt annually to 35 Mt, the situation was aggravated further.
With the SVC in operation, the voltage feeding the drives is supported at all times, with voltage sag never exceeding 3% at the 6.3 kV bus. Under these conditions, the mine hoists can be utilized more efficiently, with an improvement of hoisting capacity by some 30%. One year of operational experience has corroborated this result, with a noted increase in hoisting capacity by 25-30%.

Performance results

The contractual requirements on the performance of the SVC are listed below (Table I), together with the actually measured values with the SVC in operation. As can be seen, the SVC fulfils its tasks, as well as actually surpasses them.

TABLE I
PERFORMANCE

	Required values		**Measured values**	
	6.3 kV	**145 kV**	**6.3 kV**	**145 kV**
Max voltage variations	3%	3%	3%	1.3%
Power factor	0.98	-	0.998	-
Total harmonic distortion, voltage	4.8%	1.5%	3.2%	0.8%
Total harmonic distortion, current	5%	5%	2%	2%

CONCLUSIONS

FACTS (Flexible AC Transmission Systems) comprise a family covering several power electronics based systems utilized in AC power transmission and distribution. FACTS solutions are particularly justifiable in applications requiring rapid dynamic response, ability for frequent variations in output, and/or smoothly adjustable output. With SVC (Static Var Compensator), a member of the FACTS family, voltage stability and power quality can be maintained or improved in grids dominated by complex and heavy industrial loads such as ore mines. Voltage stabilization, in its turn, can be utilized for improved productivity in mining complexes.
In the paper, some basics as well as salient design features of SVC have been presented. Furthermore, two recent cases of SVC applications have been treated. The first for voltage stabilization of a long, weak 220 kV feeder of an ore mining complex in Australia suffering from frequent voltage drops and variations which acted to deteriorate the operation of the mine. The other for stabilizing the voltage to an iron ore mine in Sweden, enabling more efficient use of mine hoists and thereby increasing the ore mining productivity by 25-30%.

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