# Advantages of Variable Frequency Drive Technology for Face Conveyor and Plow Systems in Longwall Mining

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# Abstract

Underground mining is placing ever more demanding requirements regarding safety, efficiency and load-carrying capacity on the machines used to extract coal, and in this way is driving advances in technology.

Cat® plow systems and conveyors have proven themselves and are established in the market. Conveyors equipped with CST (Controlled Start Transmission) technology (installed power up to 3 x 1800 kW) allow soft or abrupt start through use of the motor stalling torque. Plow systems with a drive rating of 1600 kW achieve production rates up to 20,000 t/d.

More recently, frequency inverter-equipped drives have come into use and are demonstrating their capabilities compared to conventional drives: variable speeds and precise torques are available without the use of special motors, active braking of motors via energy recovery and improved overload protection for the drives protect the system components, while separate positioning of motors and inverters saves space at the ends of the face.

This paper discusses differences between conventional and variable-speed drive technology on the basis of measurements in the field and simulations. The advantage of virtual scenarios is the ability to try out new concepts and then observe the expected system responses. Analysis of dynamic processes under selected operating conditions (abrupt starts, blockage, variable process forces, overload) leads to improved understanding of the system and provides the basis for improvements.

*Cat plow system*

# Introduction

Underground mining is a world of its own: moisture, heat, dirt, noise, dust, lack of space – extreme conditions that place demanding requirements on humans and machines. Caterpillar addresses these challenges and stands for highly productive, reliable, fully automatic system solutions for the raw materials industry. The wide range of Caterpillar products includes special mining and conveyor systems for longwall mining.

This paper focuses on the plow systems used for low to moderate seam thicknesses of hard coal. The plow, a steel body fitted with picks, is attached to a continuously circulating chain that is driven from the ends of the face. It is guided along the chain scraper conveyor and cuts the coal out of the seam as it move back and forth between the ends of the face. As a rule, asynchronous motors with squirrel cage rotors plus Cat UEL overload gearboxes are used for the plow system, while gearboxes with CST technology are used for the conveyor. In recent years, inverter-fed drives have been finding increasing use due to the good control characteristics [STO15].



# Problem

The subject of this investigation is a plow system for a 250 m long face and the associated chain scraper conveyor (see Fig. 1: Overview of a plow face).

Results of simulation calculations that show the differences between the different drive technologies are presented. A good simulation model provides access to all relevant data and parameters under the widest range of operating conditions and allows new concepts to be investigated. Verification of the model used is based on existing measurements.

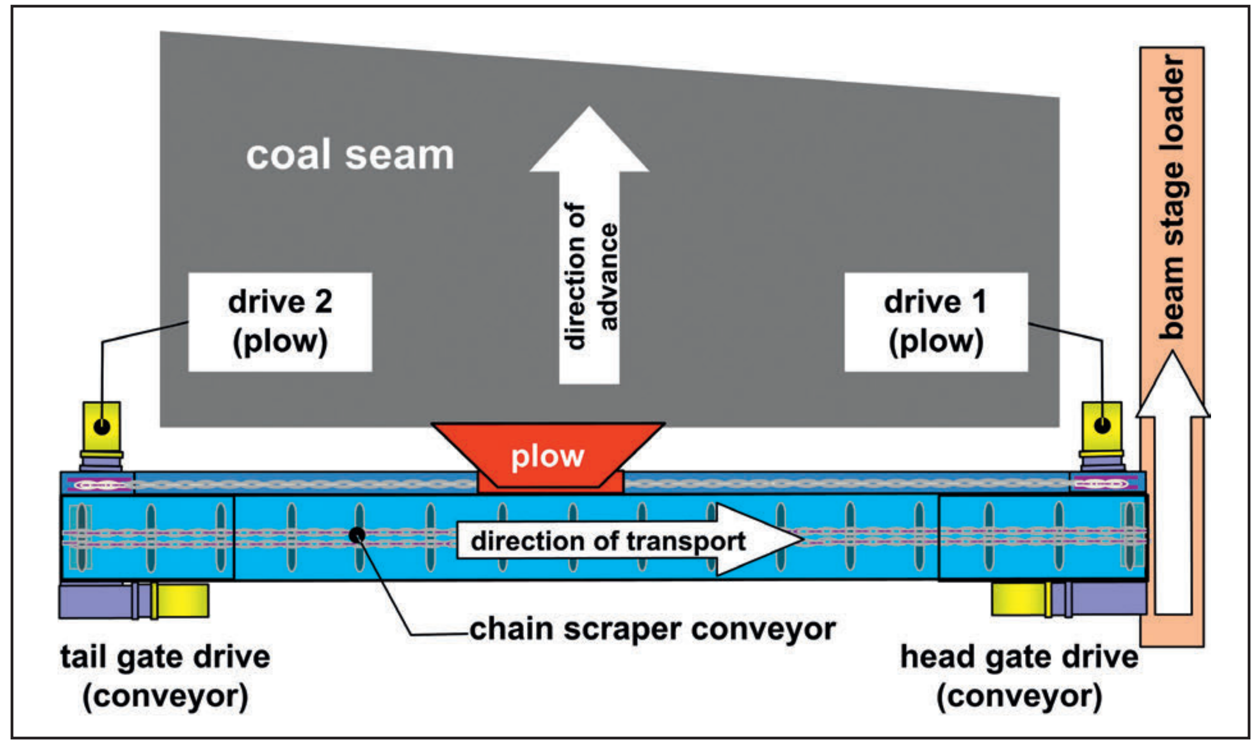



*Figure 1: System overview of a face: The plow extracts and loads the coal onto the chain scraper conveyor, which transports the coal away from the face for further conveying to the surface.*

# Model

The simulation model used represents the entirety of the plow system and a conveyor. Like the real system, the model is divided into individual components: motors, possibly a frequency inverter, gearboxes, chain wheels and chain. To observe the dynamics of the chain, a chain strand is divided into discrete individual point masses that are connected by spring and damping elements and which reflect the elastic properties of real chains (see Fig. 2: Sketch of the model used, [WAU02], [ZIE07]). Depending on the system type, the chain wheels have 5, 6 or 7 teeth.

Due to the high degree of nonuniformity, the polygon effect cannot be neglected. In addition to a mechanical part, the submodel of the gearbox contains an hydraulic part that has an effect on clutch installed in the gearbox. The asynchronous machines are presented by means of a linear model for the voltage and flux equations. The simulation model is completed through implementation of a control method that is used for the systems.

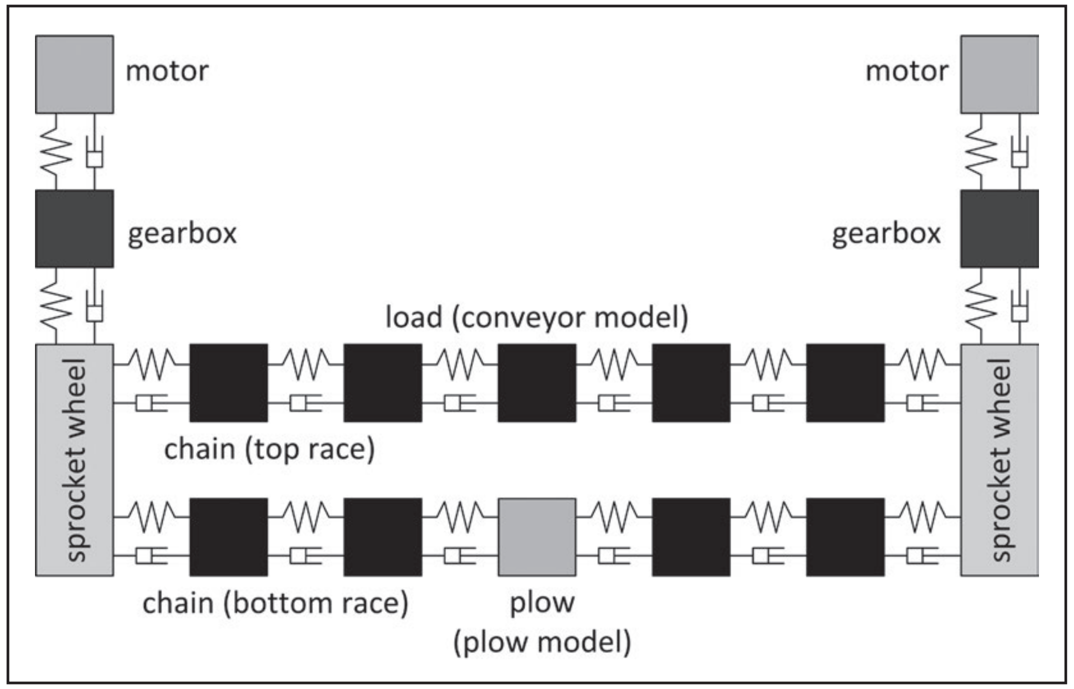



*Figure 2: Sketch of model for the plow system and the conveyor; to represent the dynamics of the overall system, it is divided into individual discrete masses that are coupled by means of spring and damping elements.*

# Discussion

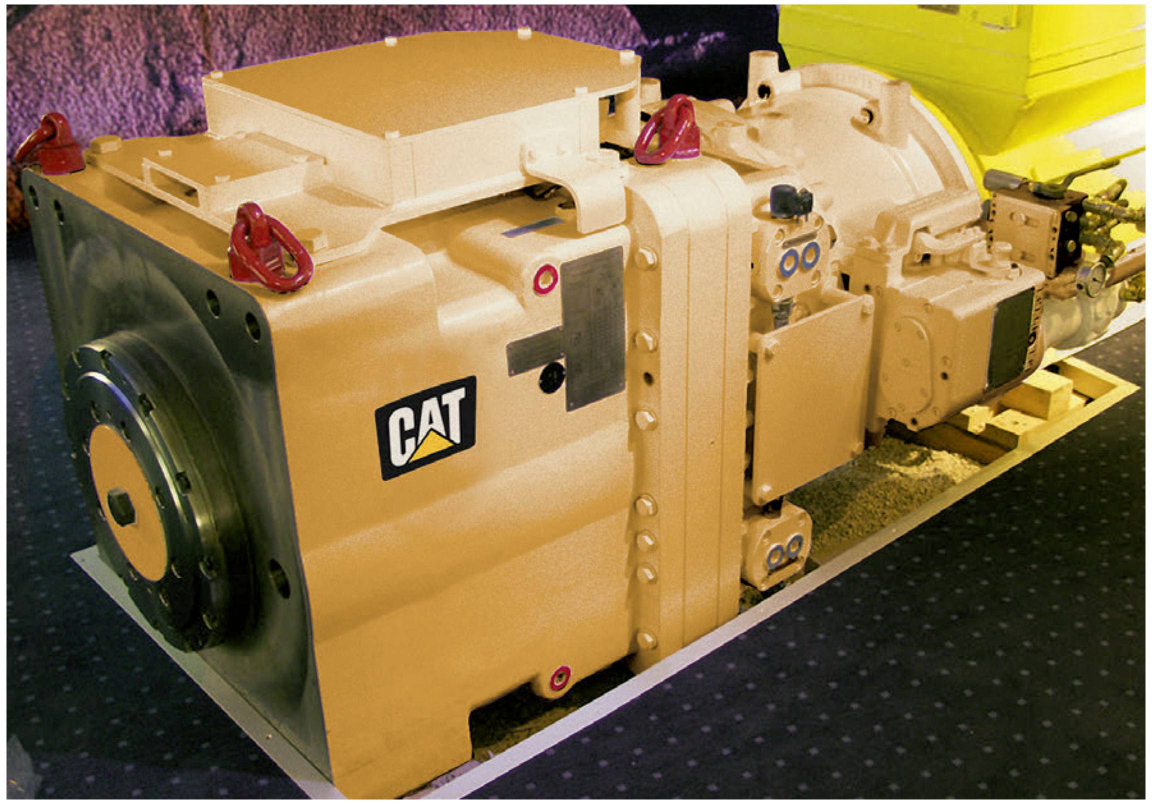
## Plow

The conventional Cat plow system consists of a plow body GH1600 that can cut seam thicknesses of 1 m to 2 m, a 42x137 mm chain, two 350/700 kW PU motors and two Cat UEL gearboxes with a ratio of 16:1, so that the plow speed can be varied between 1.5 m/s and 3 m/s. An associated conveyor for this system has a capacity of 3000 t/h. A blockage situation represents a challenge for every mining machine [AHR87, KAC87].

*Cat armored face conveyor for automated plow system*

Occlusions in the coal seam, e.g. a stray rock, immediately cause the process force present on the plow to increase abruptly compared to "soft" coal: the plow body is blocked. If there were no overload device, the chain would be pulled apart. When the plow is blocked, the chain is stretched and the drives are stalled. Because of the high moment of inertia of the drives and the transmission ratio, the forced dissipation of rotational energy would cause the force applied to the chain to exceed the breaking force of 2220 kN by far. Cat UEL gearboxes have a planetary stage where the ring gear is supported in the housing by a multi-disk clutch.

The breakaway torque of this clutch is adjustable from the outside. When the plow is blocked, the clutch begins to slip. If the slip in the gearbox exceeds a specified limit for a defined length of time, the PU motors are shut off and the clutch opens.




*Cat UEL (overload protection) gearbox*

The slipping of the clutch limits the forces applied to the chain; at the same time, the supporting residual torque from the drive end is maintained. There is thus no load shedding, which would have the same disastrous effect on the chain. In this way, the UEL gearboxes ensure safe control of the plow system in the event of blockage.

The upper graph in Figure 3: Time curve of chain force der shows the dynamics in the chain before and after the plow. The blockage occurs at time 0 s. The chain force before the plow, i.e. in the chain segment between the directly pulling drive 1 and the plow increases immediately, but remains far below the chain-breaking force because of the overload protection. As a result of the extension of the chain in both the upper and bottom races (before and after the plow body), the system settles over a time period of about 10 s.



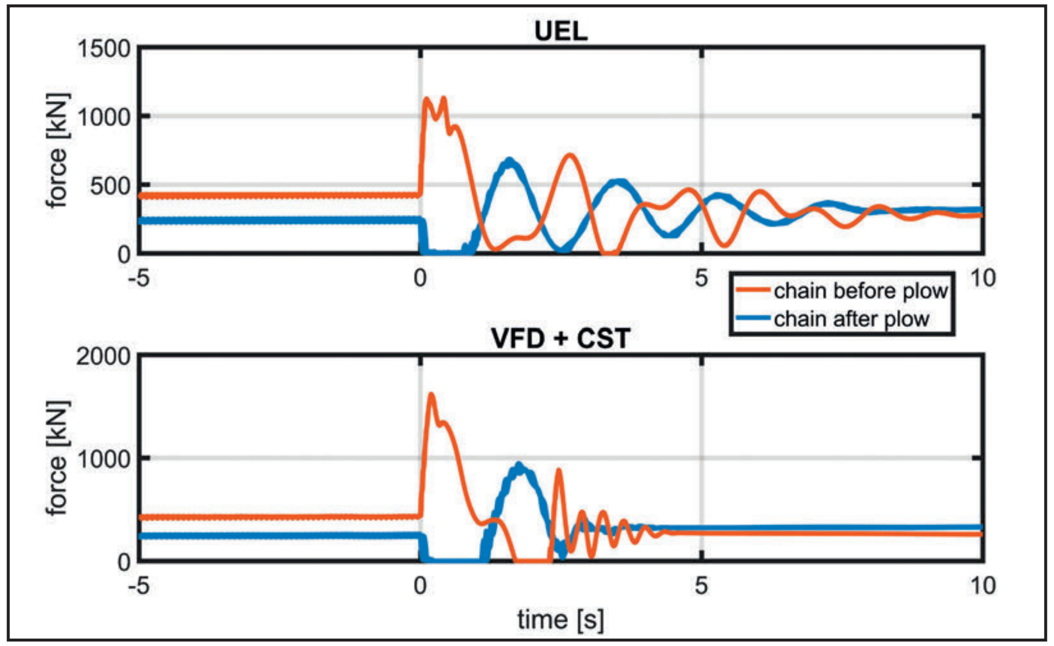



*Figure 3: The upper graph shows the time curve for the force in the bottom race of the chain before (orange) and after the plow (blue) for a conventional system with UEL gearboxes; the lower graph for a plow system with frequency inverter technology and CST gearboxes.*

Except for the gearbox, a system equipped with frequency inverter (variable speed) technology consists of the same components: In this case, CST gearboxes are used. The CST gearboxes are designed for changing speeds and contain sensitive overload protection consisting of a wet multi-disc clutch on the ring gear of the planetary output stage. Compared to the UEL technology, this clutch can also withstand continuous slip. It is thus not essential to shut down the system when the clutch slips, a situation which can be triggered by brief load peaks. In the case of blockage, there are several differences with regard to the UEL technology (see lower graph in Fig. 3: Chain force for VFD + CST).


*Cat CST (Controlled Start Transmission) gearbox*

The CST gearboxes have a somewhat higher moment of inertia. This means that the force applied to the chain is somewhat greater; as in the above case, it is far below the chain-breaking force. However, through the targeted dissipation of the driving torque the system dynamics settle faster with the aid of frequency inverters.

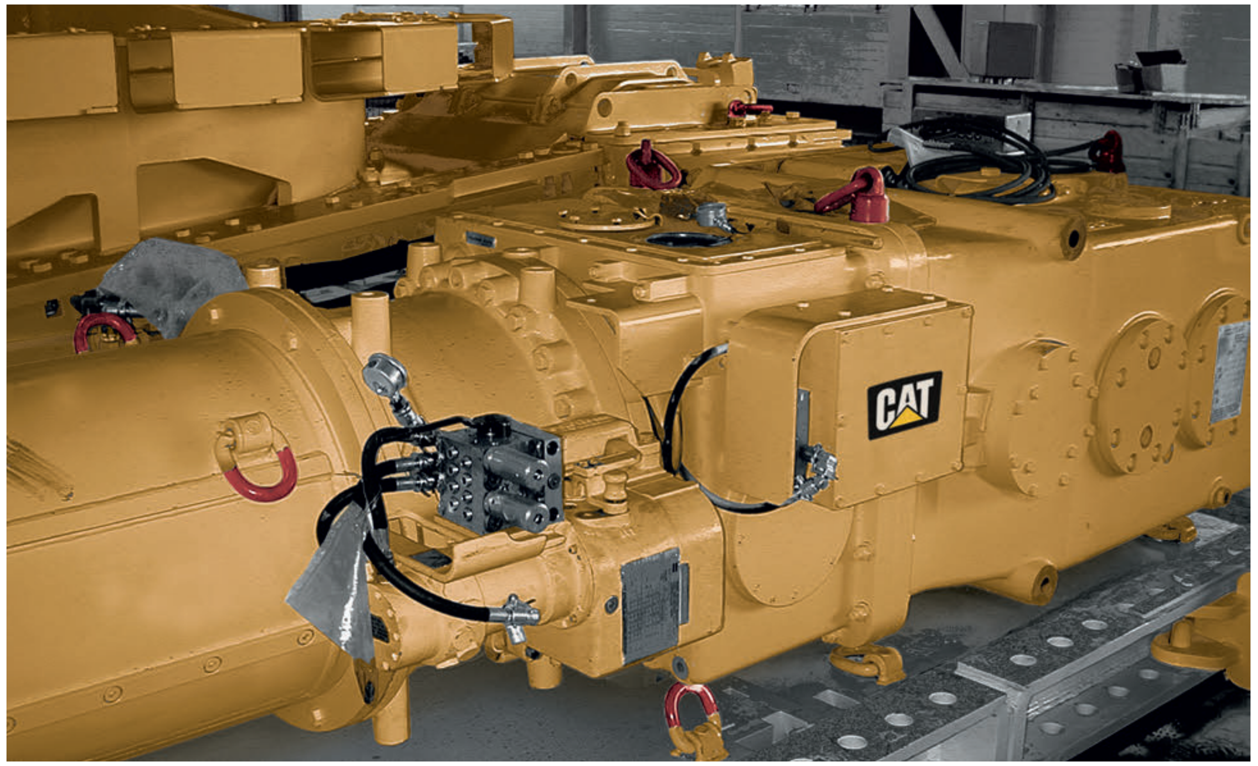
The greatest advantage of frequency inverter technology is the variable speed and the availability of the entire torque range of the motors. In mining, a situation where the drives must be operated at lower speeds occurs regularly. In a conventional system, less torque than what may be required is then available with the PU motors. A plow system with inverter-fed drives does not have this limitation.

*Cat VFD system in underground coal mine*



## Conveyor

A conventional Cat chain scraper conveyor uses CST gearboxes with a 33:1 or 39:1 ratio and asynchronous motors connected directly to the mains. The starting process proceeds as follows: the electric motors are first accelerated to their nominal speed with the CST clutch open and the conveyor is then brought into motion through targeted closing (engaging) of the clutches. In this way, it is possible in extreme cases to exploit the breakdown torque of the motors to accelerate the conveyor. During conveying, the load is balanced between the two drive ends: the CST gearboxes operate with continuous slip of about 0.2%, which is varied within limits by a load-balancing controller. This control approach permits uniform distribution of the load to both drives.



*Cat CST drive system at head gate.*

Frequency inverter technology permits a new control approach for load balancing: need-based distribution of the existing load, which protects the chain. With uniform load distribution the tail gate assists the head gate; the tail gate pulls its portion of the load indirectly via the chain wheel of the head gate. This results in an inappropriate load on the chain and chain wheel. In contrast, need-based load distribution is more advantageous: each drive handles the directly associated load and it is not until the head gate can no longer handle its portion of the load alone, that is when it reaches its rated power, that the tail gate provides assistance. Through use of this control concept, the amount of force present in the bottom race of the chain decreases and indirect pulling via the chain wheel is minimized, which has a positive effect on the service life of the components. It is obvious that this can also be applied to the plow system, where no control was provided by conventional technology.

The different load-balancing concepts and their effects can be seen clearly in the simulation results for both system types (see Fig. 4: Drive power for a conventional and for an inverter-fed conveyor). On a conventional conveyor, the power curves for the head gate and tail gate are almost identical: the two drives share the entire load in a ratio of 1:1 regardless of the sudden load increases at the times 5 s and 12.5 s. On an inverter-fed conveyor, the head gate provides more power in the initial load range up to 5 s. In the load range from 5 s to 12.5 s the tail gate contributes noticeably, as expected, when the load is higher; in the third load range beyond 12.5 s the head gate once again provides the greater part.

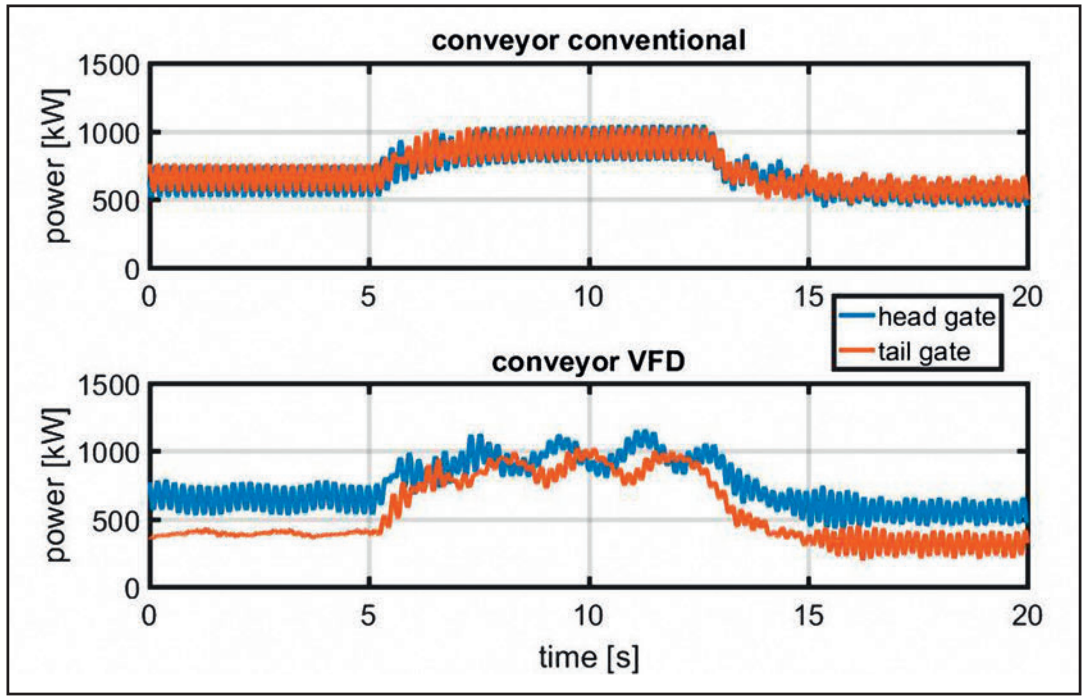



*Figure 4: Time curve of the power provided by head gate and tail gate (Ha, Hi) on a conventional conveyor (top) and on an inverter-fed conveyor (bottom). At the time 5 s the load increases; at 12.5 s the load decreases.*



# Recap

The technology of plow systems equipped with Cat UEL gearboxes and that of conveyors operated with CST technology in combination with asynchronous motors connected directly to the mains has proven itself under the widest range of operating conditions. The examples presented here show that this technology provides robust load balancing and offers appropriate protection against unexpected load situations. In this way, the service life of these systems is extended. Chain failure always represents an immense loss of production with the associated high costs.

Drives equipped with frequency inverter technology offer even additional advantages: being able to specify a variable speed and/or a defined torque permits new control approaches for the entire system, e.g. In terms of the interaction between plow and conveyor for optimal loading or improved load balancing between the drives. Having the ability to brake the plow by actively feeding electrical energy back into the grid also protects the system components. When the drives are started, the electrical system of the mine is not subjected to even further loads.


*Cat VFD system for improved speed and torque control for conveyor and plow systems*

# Notes





# Notes

Advanteges of Variable Frequency Drive Technology for Face Conveyor and Plow Systems in Longwall Mining

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