Increasingly, the advantages of using variable frequency drives (VFDs) are expanding their use as the starter of choice, not only in applications that require speed control but also in applications that require torque control and mechanical ‘soft starting’. Conveyor belt application is one such example.

Ultimately the conveyor belt starting system required for a given conveyor application needs to be defined by the conveyor designer taking many variables into consideration, such as variable speed versus fixed speed, conveyor geometry, whether regenerative braking is required or not, load sharing requirements, and many other factors. The decision can then be based on the system that provides the best balance of performance under all belt conditions, cost optimisation (including capital cost and energy cost) and reliability.

The main challenge for the designer is that the starting system must produce enough torque to get the belt load away, while at the same time applying this torque in a smooth and controlled manner to limit the negative mechanical effects of high impact acceleration. Protection against a belt jam is also important so this torque needs to be limited in case of a failure.

**VFD as mechanical and electrical soft start**

The way in which a VFD controls torque makes it the best possible mechanical ‘soft’ start method. A VFD controls the electrical quantities of voltage and frequency. The control is such that it enables a high starting torque to be developed for a very low starting current compared to direct to line. An induction motor, generally when started direct to line, develops a starting torque of around 200% and a starting current of up to seven times nominal current. Comparatively, the VFD can produce this same torque during starting but at a fraction of the starting current.

Additionally, with a VFD, this maximum torque can be decreased and limited by increasing the ramp up time. The torque developed by the induction motor follows the equation:

\[ T = k_1 \cdot \phi_m \cdot I_2 \] (1)

Ignoring the voltage drop caused by the stator impedance, the magnetising flux is:

\[ \phi_m = k_2 \cdot \frac{V_1}{f_1} \] (2)

Where:
- \( T \): torque available on the shaft (Nm)
- \( \phi_m \): magnetising flux (Wb)
- \( I_2 \): motor current (A) depends on the load
- \( V_1 \): stator voltage (V)
- \( k_1, k_2 \): constants depend on material and machine design

As the flux is proportional to the V/f ratio (taken from the second equation), and in a VFD this V/f ratio is kept constant, flux will be kept constant also. For this reason, current will be directly proportional to load torque (taken from the first equation), even during starting.

A VFD is able to deliver a precise maximum level of torque (torque limit) to the load over a precise period of time (ramp up time). An added feature, called ‘ramp hold’ makes it possible for the VFD to extend this ramp up time automatically, while maintaining the prescribed torque limit. This is useful in cases where the load is not getting away (started) with the initially prescribed torque limit and ramp up time. This can occur in situations where there is an unusually high belt load, or the belt load is wet after heavy rainfall, hence it is struggling to accelerate to speed with the existing torque limit and ramp up time settings. Refer to Figure 1:

![Figure 1: Showing the ramp hold function which is useful for achieving an optimum acceleration and deceleration time for various loading conditions. Acceleration is automatically adjusted according to the torque limit required.](Image)

As the VFD has the ability to control the torque and current, the ramp-up time and torque limit for any given application is not only completely and easily adjustable, but also accurate. The ease of directly being able to adjust these quantities is especially useful during commissioning for fine-tuning of ramp-up times and torque delivery.
Other soft starter devices can limit the torque but they do this in a less controlled manner. A fluid coupling works on the principle of creating a mechanical slip between the motor and the driven load. The motor still provides its normal high starting torque and high starting current. Instead of applying the torque directly to the load though, it is applied to the input impeller of the coupling device, and through fluid in the coupling shell. This torque is transferred in a gradual manner to an output impeller, which delivers the torque to the load. The excess torque is lost as slip energy within the coupling. The amount of torque required is determined by the level of fluid. In a fixed fill coupling this volume must be precisely pre-set to deliver the required torque during start-up, as well as providing an acceptably long start-up period. This cannot easily be changed or adjusted.

An electronic thyristor based soft starter, is another device which is able to limit the starting torque delivered to the load. It does this by reducing the voltage to the motor during starting. It is based on the relationship between voltage and torque; torque decreases to the square of the decrease in voltage. It is only possible to control the voltage to the motor, which indirectly influences the ramp up time. The ramp up time is unable to be directly controlled as with the VFD. This voltage controlled soft starter represents a very good option where initial cost is a prescribing priority.

Ramp-up curve

Besides the ramp up time which can be directly and accurately controlled by the VFD, another substantial benefit is the shape of the ramp up curve which, in the case of a VFD can be controlled and even customised. For example, the curve can be linear, s-curve, or even a combination. This can be put into effect and adjusted by a simple parameter change.

Active load sharing

The VFD has the capability to perform active load sharing between multiple motors on the same conveyor. Generally this load sharing system works as follows:

One VFD assumes the function of the master, and the others function as followers. The master VFD sends its actual speed to the follower, which the follower uses as its speed reference. The master also sends its actual torque to the follower, which the follower uses as its torque-producing current limit setting. In this way, as the master’s torque increases, the follower’s torque limit increases, allowing it to contribute more torque to the load. As the master’s torque decreases, the follower’s torque limit decreases allowing it to contribute less torque to the load. In this way an even load sharing is maintained between multiple parallel VFDs on the same load. This sharing can be fine-tuned through PID loops to obtain an accurate sharing of torque within a small bandwidth.
The droop calculated above creates a factor which is added to the VFD total speed reference as shown in the figure below. As can be seen in the above equation, the level of droop is directly related to the load torque current (iqf). For negative values of Pn, the contribution to the total speed reference below will be negative, thereby reducing output speed when load torque current increases.

![Figure 4: Showing the slip compensation block and how it adds a factor to the total speed reference to alter the actual speed. The slip compensation block acts as droop control when set to a negative value.](image)

How this works in parallel configuration when more than one VFD is connected to the same load is as follows:

Load of VFD1 increases, yielding an internal torque reference (iqf) increase. As a result, droop increases according to the formula (3), which causes a slight decrease in the total output speed according to Figure 4. VFD2 is now running slightly faster than VFD1, resulting in an increase in the load on this VFD. This increases the internal torque reference of this VFD, increasing droop and decreasing overall actual speed. This cycle repeats itself until loads are balanced.

![Figure 5: Showing droop control sharing of loads for a three-VFD conveyor system. The VFDs are labelled master, slave 1 and slave 2 purely for reference.](image)

**Speed variation**

While it is true that speed variation may not be always be necessary for many conveyor applications, the starting advantages, protection advantages and control advantages of VFDs alone are enough to warrant their selection for conveyor applications.

In those applications that do warrant speed variation, VFDs represent the most efficient and effective way to achieve this. Energy saving during low process demand periods is entirely possible as demand power decreases linearly with respect to speed. This speed control is also useful in that it can be used to maintain constant conveyor speed by automatic adjustment of the torque response to load changes. Alternatively it can be used to maintain constant conveyor torque by automatic adjustment of the speed response to load changes. Speed change can also be implemented from a process perspective, to decrease speed during low demand periods. An example of such a scenario is shown in Figure 7.

![Figure 7: Showing speed change in relation to process demand change on an overland conveyor system, and the corresponding change in power. The above trend is taken from a single belt with master-follower application of three 600 kW motors on VFDs.](image)
Conclusion

In addition to the mechanical and electrical benefits of VFDs already mentioned, it must also be remembered that VFD offers a complete system protection means against overload, over-voltage, under-voltage, short circuit and with the ability to ride through voltage dips. It is also possible to start multiple motors using the same VFD and synchronised line bypass.

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