The Right Drive to Maximize Efficiency and Production for Large Overland Conveyors

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ABSTRACT:

This paper examines various drive systems available for large overland conveyors, with special attention to starting and operating methods with respect to 2 most commonplace drives, the VFD (for squirrel cage induction motors) and the SRC, secondary resistive controller, (for wound rotor induction motors). Regenerative conditions, load sharing considerations, starting and stopping duties, as well as special requirements for variable speed are described, with overall system efficiency and reliability scrutinized. There is no one right drive for every application; the best suited drive will depend on many project-specific factors, described herein.

Although extensive engineering goes into designing the best large overland conveyor for a unique project, sometimes less design time is invested on selecting the most appropriate drive. Typical key considerations for high level conveyor design are terrain geography, material type conveyed, present and future capacity requirements, environmental factors, service duty, and optimizing capital and maintenance costs. Without too much thought, one can assign variable frequency drives (VFD) to operate the conveyors, due to its versatility and wide general acceptance. With a VFD driving a large overland conveyor, the exact full load running speed can be optimized at any time, and the conveyor can be sped up slightly for increased capacity at a later date. However, the VFD is often not the most efficient or cost effective drive option for many large overland conveyors. Below, we summarize various drive types, and identify key factors in selecting the most suitable drive for large overland conveyors to maximize both efficiency and production. The choice of drive will vary depending on the project specifics as well as the unique operational requirements of the overland conveyor.

Overview of Select Common Large Conveyor Drives

There are many acceptable drive options for starting and controlling large overland conveyors. Three of the most common drive types are fixed or variable fill fluid couplings (FC), variable frequency drives (VFD), and wound rotor motor resistive controllers such as liquid rheostats (LR) and binary coded secondary resistive controllers (SRC). Electronic soft starters are also used to limit current inrush in conjunction with fluid couplings, however they are not typically used on their own for large overland conveyors due to their limited torque delivery capabilities.

The fixed fill fluid coupling is a mechanical drive solution which is cost effective and therefore, more suitable for smaller single drive conveyors (<1000Hp, 1 motor). Fluid couplings are most commonly used with “standard” squirrel cage induction motors (SCIM). Load sharing necessitates more stringent maintenance of the fluid couplings to allow for predictable load balance among the multiple drives on a common conveyor and can be cause for problems and unplanned downtime. The starting profile is also compromised over time without adequate fluid coupling maintenance, resulting in changes to the ideal starting torque profile. These changes can result in the acceleration being too fast or too slow, as well as causing multiple drives to become significantly unbalanced on a common application.

With a more costly variable fill fluid coupling, the starting profile can be controlled depending on load requirements, by adjusting the fluid fill to control torque and speed during an acceleration cycle. This type of fluid coupling can also be used for jogging an empty belt and is better suited to adjusting for load imbalance among multiple drives on a common application. However, this type of fluid coupling is also more maintenance intensive, due to the number of moving parts, reservoirs, pumps, piping, instrumentation, etc., and is thus less reliable.

VFD Characteristics applicable to a Large Overland Conveyor

The variable frequency drive (VFD), also known as a variable speed drive (VSD) or variable voltage variable frequency drive (VVVF drive) is a common electrical drive solution for large overland conveyor applications. It is cost effective for smaller horsepower (Hp), low voltage (LV) conveyor applications, and is best suited for conveyors that require continuous speed variation at relatively constant load. The VFD is usually NOT the best-suited drive for conveyor applications where the only variable speed required is for starting and/or stopping. VFD’s for larger Hp, MV motors are costly, and require special installation considerations.

The following standard characteristics are considered in this paper for VFD applications on large overland conveyors:

- VFD’s are composed of sensitive electronics and must be installed in a clean environmentally controlled environment such as an electrical room with adequate cooling and dust control. If the plant E-house is to be considered, this translates to space and cooling requirements with associated costs.

- VFD’s generate harmonics which can be detrimental to the electrical system connected equipment and must be filtered and/or managed accordingly.

- With the associated electronics, VFD’s must have considerable cooling in the form of an air to air heat exchanger (with additional installed HVAC capacity) or liquid to air heat exchanger (with pump skid and heat exchanger outdoors). For reliability, redundant cooling systems are often specified.

- Typically, a specialized VFD technician is required for set-up and commissioning as well as trouble shooting of the VFD. Over time, manufacturer firmware upgrades are also required to keep the VFD current with technological developments.

- An isolation transformer is required for the VFD. Also, often at higher Hp or at higher site elevations, VFD's are offered with voltage ratings different than what is standard at site. When this is the case, a step down transformer is also required to accommodate the difference from site distribution voltage.

- For conveyors with more than 1 drive required, the VFD needs to remain connected in the system to allow for adequate load sharing between the multiple conveyor drives. Bypassing the VFD in this situation is not an option.

Typically used with a SCIM, the VFD controls the torque and speed applied to the conveyor by varying the input voltage and input electrical frequency to the motor. During controlled acceleration and controlled deceleration modes, the VFD is the most efficient drive solution ***if*** the loading is kept constant and at nominal rated capacity with respect to the motor and VFD rating.

On their own, motors constructed for VFD's are slightly less efficient (~1%) due to the optimization of motor design characteristics making it more suitable for VFD use. Additional motor efficiency loss occurs when connected to the VFD due to the harmonic content of the VFD supply.

For most large overland conveyor applications, the VFD and SCIM are sized larger than nominal running load requirements to allow for additional high torque breakaway conditions in addition to typical conveyor design safety factors.

Secondary Resistive Controller (SRC) Characteristics applicable to a Large Overland Conveyor

As an alternative to VFD or FC drive solutions, the secondary resistive controller (SRC) is a reliable drive solution, with negligible owner maintenance requirements. Connected to the secondary or rotor circuit of a wound rotor induction motor (WRIM), resistive controllers such as the SRC vary the resistance of the rotor circuit, effectively changing the motor characteristic. With specific resistance connected to the rotor circuit, the motor can effectively apply torque to the load in its optimal operating range, where the current and torque are within nominal steady state ratings of the motor, at *any speed*. Additionally, with specific connected resistance, the motor can apply any torque up to the rated motor breakdown torque at any speed in response to a conveyor's high breakaway torque requirements at relatively low currents. This eliminates the need for over-sizing the drive system to accommodate for high conveyor breakaway conditions. By varying the resistance connected to the WRIM rotor, the SRC can allow the motor to apply specific torque at any speed during the acceleration cycle.

The graph in image 1 below depicts four different torque vs. slip characteristics resulting from four specific connected resistance amounts with a standard WRIM. The blue curve represents higher resistance, and the black curve represents zero external rotor resistance. Note that the left side of the torque curve is used for controlling the conveyor speed. Adding more resistance than shown will lower the torque applied at stall in the usable portion of the speed torque curve.

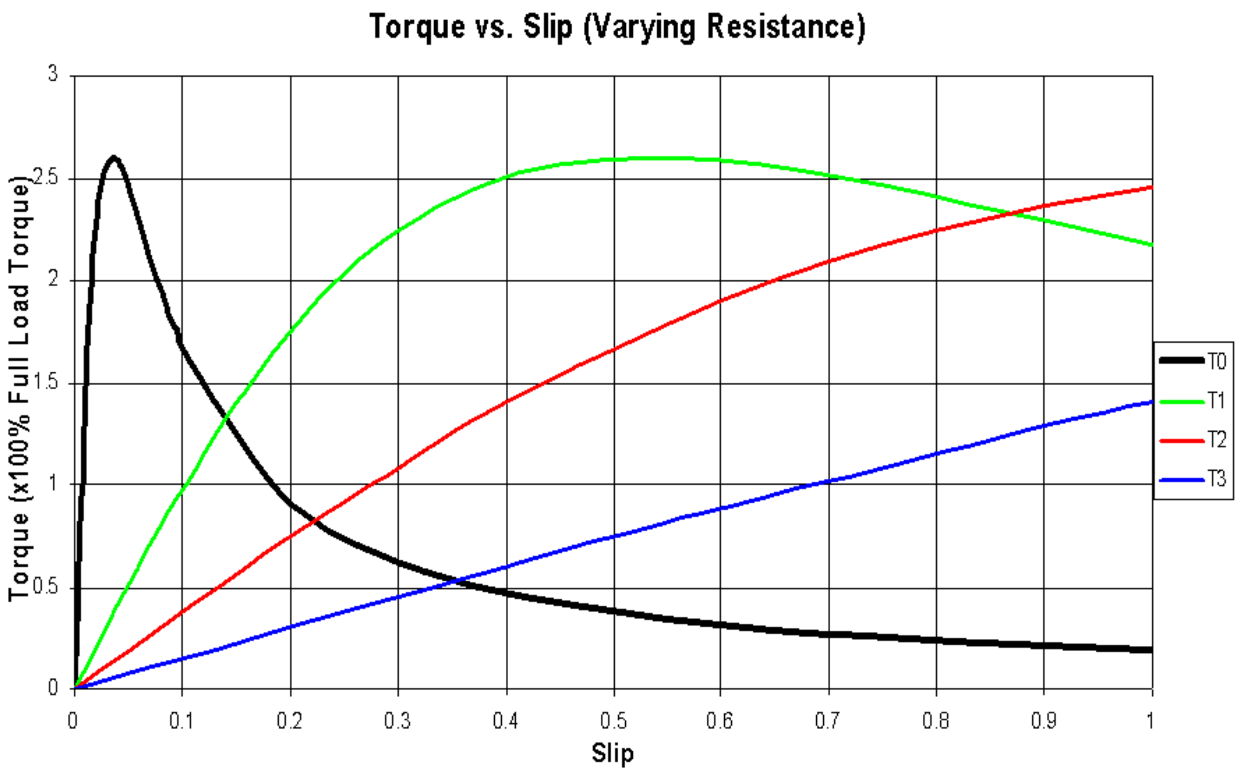

Image 1: Torque vs Slip WRIM characteristics with 4 different values of external resistance connected to the rotor.

The SRC is a cost effective drive solution for larger Hp conveyor applications (>1000Hp) and for conveyors with more than 1 motor. The SRC solution is the most efficient drive system for constant speed applications, ie in running mode. Although conveyor acceleration (starting mode) is less efficient than the VFD solution, running is more efficient. For example, starting a conveyor 3-6 times per day, and otherwise operating it at constant speed, annual energy consumption is less using the SRC system.

The following standard characteristics are considered in this paper for SRC applications on large overland conveyors:

- The SRC has high operational efficiency.
- The SRC solution is very reliable due to the fact that it is composed of vacuum contactors for resistance selection, PLC control, and stainless steel resistor grids. With very few components and components that are industrial in nature, reliability is extremely high.
- The operational life due to standard simple components is typically 20+ years. In our experience (hundreds of installations world-wide) we have had zero failures and zero downtime to date.

- Because the SRC is not sensitive to environmental factors such as dust, weather, and altitude, it is extremely robust and can be installed virtually anywhere, thereby saving valuable E-House space. No additional cooling is required for the proper operation of the SRC.

- With no high frequency switching required, the SRC does not generate any harmonics.

- Comprised of simple components, the SRC is maintainable by mine personnel. Typically, the only maintenance required is blowing out the dust that settles on the resistors and contactors if the drive is installed outdoors.

- For multiple drives on a common application, load sharing is achieved by adding a small amount of resistance to the drive drawing more power. This simple adjustment is performed once by a site electrician at time of commissioning, with a fully loaded conveyor. Naturally, at no time does one drive attempt to work against another.

- Although not very efficient, jogging or creeping the belt for maintenance purposes is available without additional equipment.

- For unloaded situations, or for emergency situations, dropping off or picking up motors on the fly with the SRC + WRIM system is a simple procedure. Because the input frequency is that of the mains, electrical synchronization is not a concern.

- Because the SRC + WRIM system operates on the natural characteristic of the induction motor, moving from motoring to generating for a downhill conveyor is seamless. This is the natural response of the induction motor. The SRC is not required to control this transition and therefore the high efficiency is that of the WRIM.

- Out of all the above drive solutions, the SRC results in the lowest motor heating and therefore, the least amount of motor stress, and higher number of starting cycles per hr capability.

At normal running speed the operating efficiency (both in motoring and generating modes) is that of the wound rotor induction motor (WRIM). WRIM's typically have higher efficiencies (~1%) than SCIM's designed for VFD's. This is due to the fewer constraints on WRIM designs if they are not being applied to VFD sources.

Liquid Rheostat Characteristics

Although the liquid rheostat (LR) is a cost effective apparatus (from a capital cost perspective only) designed to control the resistance connected to the rotor circuit of a WRIM, it is not ideally applied to large conveyor applications due to the following limiting factors of the LR:

- The liquid rheostat resistance is strongly dependent on the temperature of the electrolytic liquid, and therefore no 2 starting profiles are the same.

- A smooth, seamless start can be achieved through most of the starting cycle, but the LR cannot reduce the connected rotor resistance close enough to the short circuit resistance (0 Ohms) to eliminate a torque and current spike as the last of the connect rotor resistance I shorted out by the shorting contactor. This torque (current) spike can cause belt slip, and reduces the motor insulation life. See the chart recording in Image 2 below of a typical liquid rheostat starting cycle. Note the current spike at the end of the start.

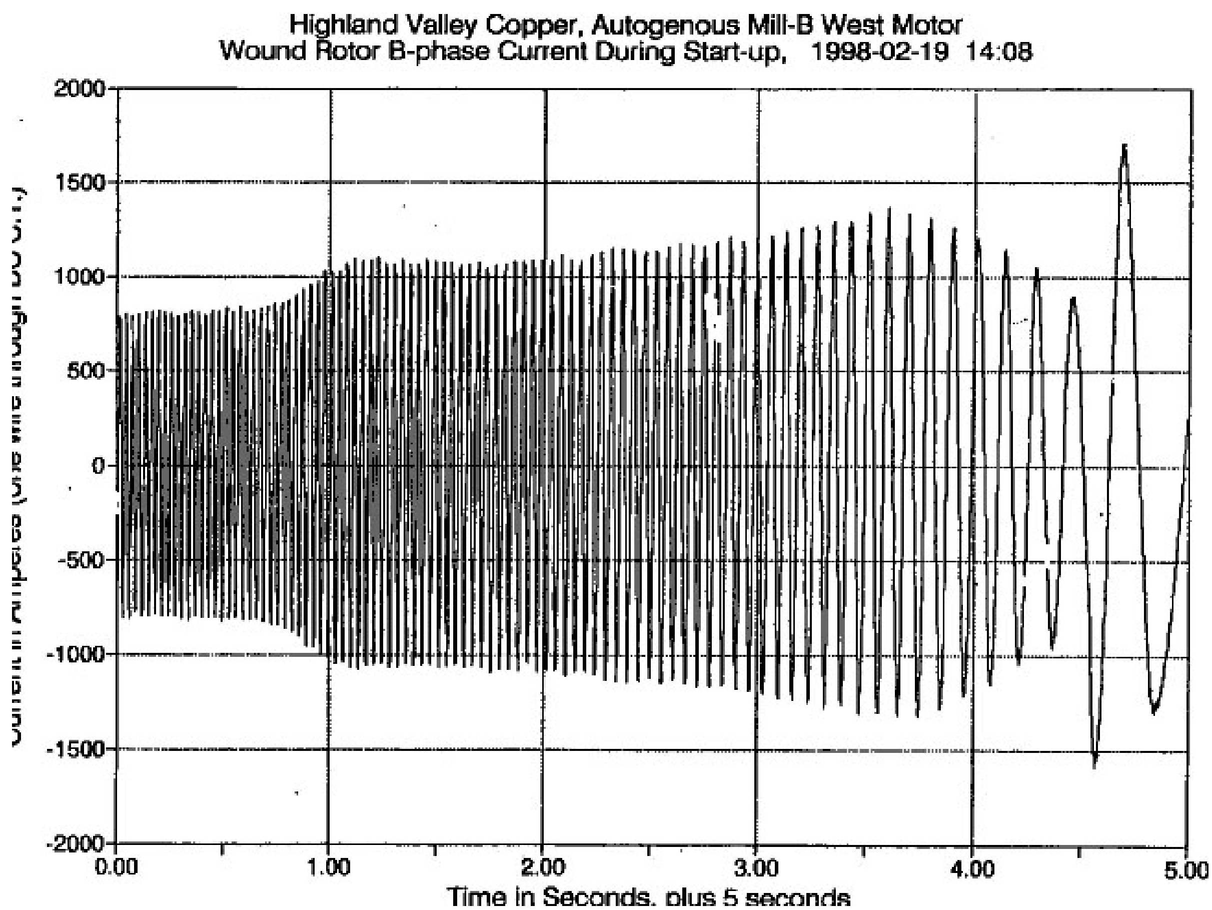

Image 2: Liquid Rheostat starting cycle with torque (current) spike upon start-up completion.

- Load sharing is typically accomplished with external solid resistors and is an extra cost.

- Due to the nature of its components, the LR requires frequent maintenance. In particular, if the electrolyte is not kept balanced and well cooled, the starting profile and torque spike can become unacceptable for a large conveyor application.

Over time, any cost savings with the liquid rheostat are overshadowed by maintenance costs. For smaller overland conveyors with frequent starting requirements, the maintenance costs can exceed any capital savings in as little as 2-3 months. More importantly, the characteristics of LR starting as noted above make it less suitable technically for use as a conveyor controller.

Technical Considerations for Selecting the Most Appropriate Drive Type

In selecting the best suited drive for a large overland conveyor application, one should consider how efficiently the drive in question operates with respect to the system requirements. The following block diagram in Image 3 looks at a high level arrangement of the two most appropriate drive systems for large overland conveyors for the purpose of system efficiency comparison.

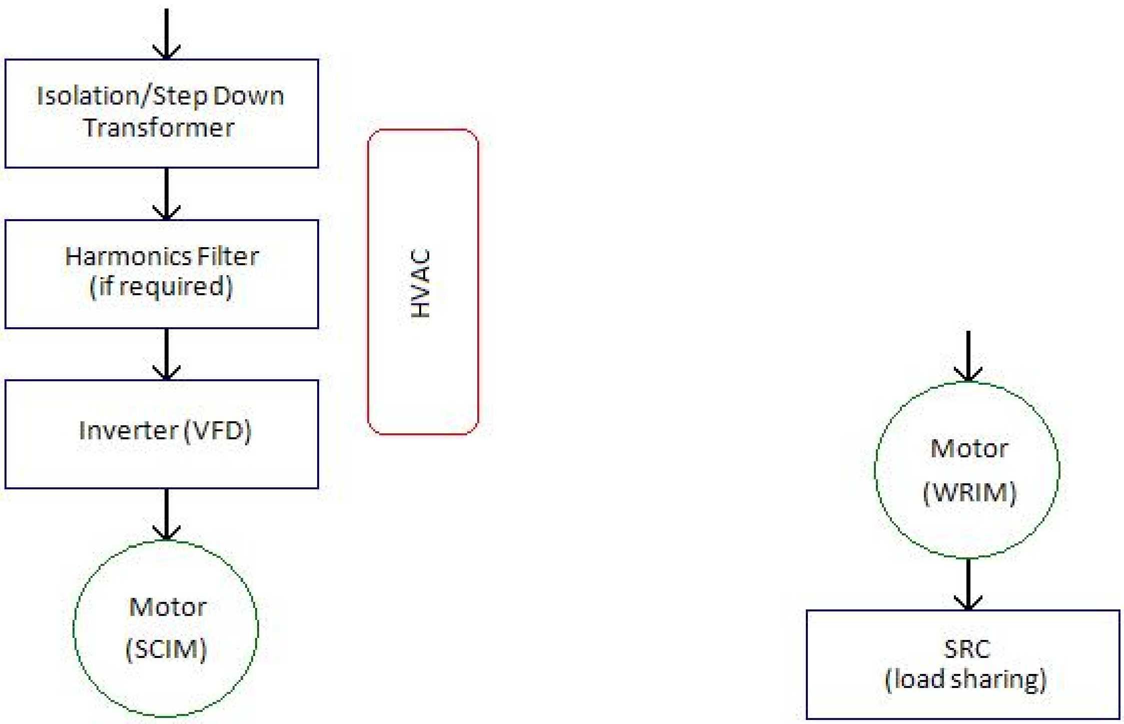

Image 3: A high level block diagram of the VFD system (left) and a high level block diagram of the SRC system (right)

During steady state motoring, the VFD system, with components connected as shown above, is less efficient than the SRC system. Here we assume that the drive systems cannot be bypassed due to multiple motors on a common overland conveyor system requiring load sharing. The VFD and both the WRIM and SCIM are at their optimum operating efficiencies at their rated load.

At rated load, typical efficiencies of some of the above components are: 98-99% for the transformer; 95-96% for the inverter; 94-95% for the SCIM (on its own); and 95-96% for the WRIM. The SCIM loses additional 1-2% efficiency when operating off a source with harmonic content, such as a VFD. Further system losses occur in the harmonic filter if it is required, and in the HVAC system for the electrical room housing the VFD. If VFD cooling is required in addition to the enlarged E-house HVAC system, additional power would be consumed.

On the SRC side, he WRIM is connected directly to the mains, and the SRC is connected to the rotor or motor secondary circuit. The SRC resistance is connected during starting mode and otherwise, it is bypassed. For multiple motors on a common conveyor, if the motors do not share load evenly under full load conditions, then a small amount of resistance is connected to the rotor of the motor drawing more power to even the motors out. In this case, there is an efficiency loss of <1% in the SRC being used.

Under steady state generating, such as a downhill conveyor, Image 3 can be referred to with the power flow in reverse, assuming the VFD system is a 4-quadrant system with regenerative capabilities. That is, similar losses exist as with the steady state motoring scenario. With the SRC system the motor is already connected directly to already synchronized with the mains. The power in the SRC system does not flow through any efficiency-compromising components from the motor to the mains, making it more efficient than the VFD system.

If the conveyor requires only a single drive, negating any requirement for load sharing, both the VFD and SRC systems can be bypassed, leaving the motor as the only point of efficiency loss in this drive comparison. In this case, the WRIM is only ~1% more efficient than the SCIM as explained above.

As is often the case, conveyor loading is not constant and is not typically at maximum rated load with respect to the installed motor power. In this case, assuming constant (full) operational speed, the SRC system efficiency degrades much less than the VFD system. Both the SCIM and the WRIM degrade relatively equally with decreasing load. However, the VFD has relatively fixed losses regardless of load, whereas the SRC, if it is required for load sharing, has decreasing losses proportional to the decreasing load. Therefore, as load decreases, the VFD efficiency decreases, but the SRC efficiency remains constant. Note that, in the case of evenly loaded multiple motors on a common conveyor application, the SRC can be bypassed, leaving the motor as the only point of efficiency loss in the WRIM+SCIM system.

Under constant load, *variable speed,* the VFD system efficiencies exceed that of the SRC system. Under starting, stopping and changing conveyor speed, the SRC system uses resistance to change the torque-speed characteristic, which is not as efficient as the VFD system of changing the input volts/Hz ratio. Furthermore, the SRC system cannot regenerate braking energy back to the mains. However, under low load and low speed conditions, such as creeping an empty belt for maintenance purposes, the energy dissipated in the SRC is minimal because it is proportional to the low load. In the creep case, the VFD is only slightly more efficient than the SRC due to the VFD's relatively fixed losses independent of load, resulting in a decrease of VFD efficiency under low load conditions.

Finally, system power factor (pf) should not be ignored. Under low load conditions, motor pf degrades. Typical motor pf curves with respect to load are relatively flat, but fall off at very low loading conditions.

The VFD system can correct pf to unity under most loading conditions, whereas the SRC system cannot. Note that low loading negatively impacts motor efficiency as well as the VFD drive system efficiency.

When operating at very low loads, dropping off some of the conveyor's motors becomes desirable. By running the conveyor with fewer motors, the system efficiency is increased. In the case of the SRC system, operating with fewer motors also increases the motor pf. Dropping off and picking up motors on the fly is simple for the SRC system because synchronization with the mains need not be considered. Dropping off and picking up motors with the VFD system is a complex operation, if it is possible at all, because exact synchronization is required.

Application Considerations for Selecting the Most Appropriate Drive Type

In selecting the best suited drive for a large overland conveyor application, the technical merits described above are not the only considerations. In addition to considering the drive application, factors due to location should be considered as well as how the conveyor will be operated.

Considering first the drive application, VFD's are better suited to applications that require continuous speed control under relatively constant load conditions. In this type of application, the VFD is the most efficient drive solution out of all those presented herein. Note that under variable load conditions, the VFD system becomes less efficient with decreasing load.

Practical Considerations for Selecting the Most Appropriate Drive Type

Next, consider the aspects of location: Site geographical location; site elevation; and drive installation location on the site.

A more complex drive solution, such as a VFD for an overland conveyor system, typically requires expert assistance in site commissioning and start-up support. Additionally, troubleshooting and VFD firmware upgrades may require the visit of the manufacturer's representative. Depending on ease of access to the site, and the distance of the site from the VFD specialist, this may result in high costs and unacceptable downtime waiting for the factory specialist. In contrast, the SRC is simple in design, with standard electrical components that most site electricians are experienced with. At most, the PLC program may need to be optimized for actual starting dynamics, which can be sent electronically and uploaded to the SRC PLC by any site personnel with PLC experience. If any SRC troubleshooting is required due to an unexpected failure, all components are easily inspected and can be changed out as necessary by site maintenance personnel.

Site elevation also becomes a consideration for many mine locations. The SRC can be easily de-rated for elevation with adjustment in cable and bus size and spacing between live parts. The WRIM input voltage is not affected and site standard distribution voltage can be utilized. The VFD on the other hand, may require the supply voltage to be suitably de-rated for proper operation at elevation, resulting in a non-standard voltage supply to the VFD, and a non-standard motor primary voltage. Cable sizing becomes quite large for large overland conveyor VFD applications at elevation.

On site, VFD's for large overland conveyors typically require installation inside an environmentally controlled electrical room, with adequate cooling within the electrical room or via a separate heat exchanger outside the room. It is not uncommon for an electrical room to require redundant HVAC systems if a large conveyor VFD is installed therein, relying on the cooling system for uninterrupted function. Suitable space outside the electrical room is also required for the isolation and/or step down transformer. This can impact the size and cost of the electrical room significantly. Not only is the design of the electrical room a factor for the VFD installation, the location of the electrical room with respect to the location of the drive motor should be considered. Due to cable sizing and harmonics reflection considerations, the room should be located relatively nearby the drive motor. Due to the simple components and the lack of additional cooling required, the SRC can be installed in most environmental conditions, separate from the main electrical room, and close to the motor. The SRC installation therefore does not require HVAC considerations, or space requirements as part of the electrical room design and cost.

Operational Considerations for Selecting the Most Appropriate Drive Type

Finally, in deciding on the best drive for the overland application, the anticipated operation of the conveyor should be considered. If the conveyor will be started and stopped many times per day, a VFD can be the more efficient solution. Likewise, if the conveyor is constantly varying speeds, the VFD efficiency is better than the SRC efficiency. However, under full speed operation, with varying load conditions, the SRC solution is more efficient.

Considering the factors presented herein, the nomination of one drive type over another for a large conveyor application is not straight forward. The factors above point clearly to one drive over another in a given technical situation, but the importance of the above factors evaluated against importance of the unique characteristics of the different drive types must also be considered. The following lists a selection of examples where one drive might be considered over another for a particular driving factor:

1- The conveyor is started and stopped 3-6 times per day, and otherwise operated at full speed with varying load conditions. The client considers efficiency to be most important. → SRC

2- The client wants the most reliable drive solution because they are situated in a remote geographical location, with poor access to drive specialists. Availability of the conveyor is of paramount importance. If any troubleshooting is required, it must be done quickly and by site personnel. → SRC

3- The client plans to operate the conveyor with frequent start and stop cycles, and/or with variable speed. Efficiency is most important. → VFD

4- The client is operating a regenerative conveyor underground, where any heat generated from stopping the conveyor is difficult to deal with. Regenerating the energy back to the mains is a top priority. → VFD (4-quadrant, fully regenerative type)

5- The client needs the flexibility of dropping off or picking up motors on the fly to improve system efficiency or increase the conveyor availability in the event of a drive system problem on the multiple drive conveyor. → SRC

Unique Considerations for the Selected Drive Type for Successful Application

Selecting the best-suited drive for a particular conveyor application may seem academic at first, but depending on many drive and application/site factors, it can become an evaluation of tradeoffs, which will depend on the ultimate interests of the client. Not only the characteristics of the drive type need to be considered in relation to the overland conveyor requirements, the needs and limitations of the end user also play a significant role. It's only after selecting the most optimum drive solution that one must identify the unique considerations for the drive design itself to meet the application requirements. These include but are not limited to:

- sizing the drive for conveyor breakaway torque requirements
- sizing the drive for the desired starting and stopping torque profiles
- reduced current inrush upon starting
- pre-tensioning the conveyor belt as part of mechanically soft starting the belt to avoid belt slip
- accommodating for enough torque delivery to clear plugged chute conditions if the conveyor is fed with one or more chutes
- keeping the drive size as close to the normal rated load running conditions as possible to maximize efficiency and minimize costs

In Summary

As demonstrated above, there are many factors to be considered to select the best-suited drive type for a large overland conveyor. These design considerations should be presented early on in the overall conveyor design phase to maximize both efficiency and production of the resulting operation. All too often, the drive is selected as an afterthought to accommodate for all possible (and impossible) operating scenarios of the conveyor system, with resulting operational cost impact. In examining operational details in cooperation with unique drive characteristics, the importance of designing the drive type into the overall conveyor system design become clear. One drive does not fit all conveyor applications; there is always a “best fit”.