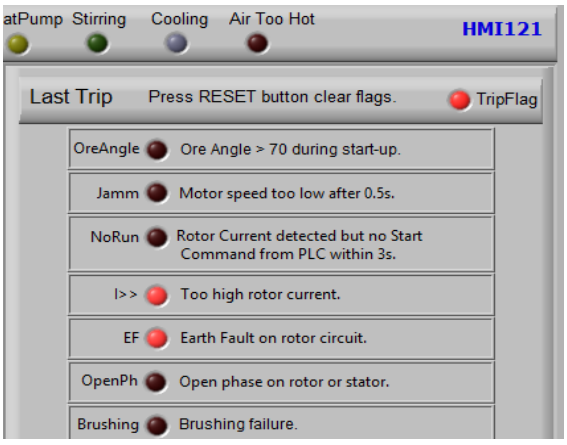
Advanced LRS/Mill Safe Start : Five systems in one.

The ALRS/MSS works in 5 ways to protect you grinding mill:

- Remote Performance monitoring of LRS
- Remote Root Cause Analysis.
- Remote Fault Detection and Prevention
- Protection
- Optimal Control

This function overview document focuses only on the Protection functionality.



SDG TECHNOLOGIES

Overview

After many years of analyzing rotor side recordings of the start-ups of grinding mills and witnessing many rotor side electrical faults, it became clear that several mill-focused rotor side specialized protection functions would greatly enhance the primary stator-side protection, in many cases preventing or greatly reducing damage and down-time.

The ALRS/MSS includes the following unique rotor-side protection functions:

1. OreAngle (Locked Charge Protection, checks that the ore has tumbled before mill reaches 70°)
2. Jamm (Checks adequate motor speed after 0.5s)
3. NoRun (Prevents boiling of the water if the PLC start command gets lost)
4. I>> (Special sensitive Instantaneous Overcurrent tailored for rotor-side application)
5. EF (Special Rotor E/F)
6. OpenPh (Detects brushing failure extremely quickly while starting, preventing likely earth fault.)
7. Brushing (Detects brushing failure while the motor is running at full speed.

Each fault condition is clearly indicated on the HMI, ensuring accurate fault identification.

Although analogues can be made with standard IEC and IEEE protection elements, it should be realized that tailoring the protection to the rotor circuit on the mill-specific application presents unique opportunities and comes with unique challenges. For example, the frequency of the rotor circuit varies widely, and it is therefore not possible to use standard protection algorithms that assume a fixed system frequency.

As another example conventional I>> elements have to be set above the Shorting Spike current to avoid nuisance tripping. The Mill Safe Start I>> element takes this into consideration, with the timing of the shorting contactor included as a setting. It therefore anticipates the Shorting Spike and protects the preceding start-up correctly, at a sensitivity that would have been impossible if the Shorting Spike had to be included.

Slip Ring Flash prevention

This is one of the most common rotor circuit faults and more often than not causes much damage, necessitating change-out of the motor.

The protection elements most applicable to preventing such an incident are:

1. Open Phase element (OpenPh). Used to detect brush failure during start-up.
2. Brush element. Used to detect brush failure during mill running.
3. EF element. Trips instantaneously should an earth fault occurs on the rotor circuit, in time to prevent damage.

The standard stator-side motor protection typically only trips the motor when enough damage has been done to necessitate a change-out of the motor, resulting in much more downtime.

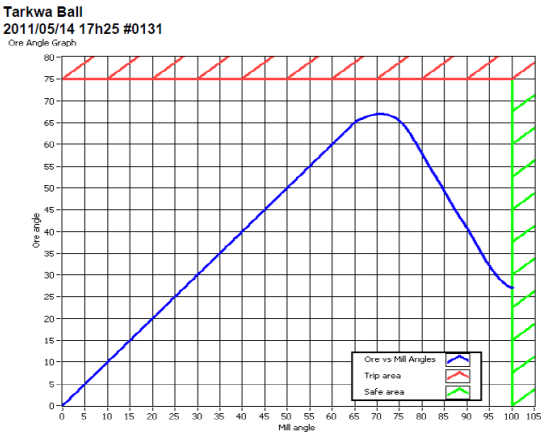
The Mill Safe Start measuring position on the rotor side between the motor and the LRS affords a unique opportunity to detect the fault immediately (within 1ms) and issue an instantaneous trip. The rotor windings are not earthed in the motor, the only path to earth is therefore through the LRS. Any earth fault on the motor / slip-ring side of the Mill Safe Start CTs can therefore instantaneously be detected, as some current will bypass the CTs, flowing from the earth fault directly to earth, and the sum of the CTs will therefore not be zero as it should be.

As there are high resistances in the rotor circuit at this point limiting fault current, it is generally not possible from the stator side to detect the single phase earth fault, and the motor is only tripped when the fault has developed into a three phase fault, and even then the standard over current protection is slow enough to ensure extensive damage. (Depending on the motor speed, i.e., rotor voltage, at the time when the earth fault develops into a 3ph fault. If early enough in the start-up, there is a chance to trip I>>, else there is no way to avoid a lengthy IDMT and much damage with conventional protection.)

OreAngle

The ALRS/Mill Safe Start System calculates the ore angle in real time during the start-up, and the mill is tripped if the ore is cemented, before it can drop and damage the mill bearings and structure.

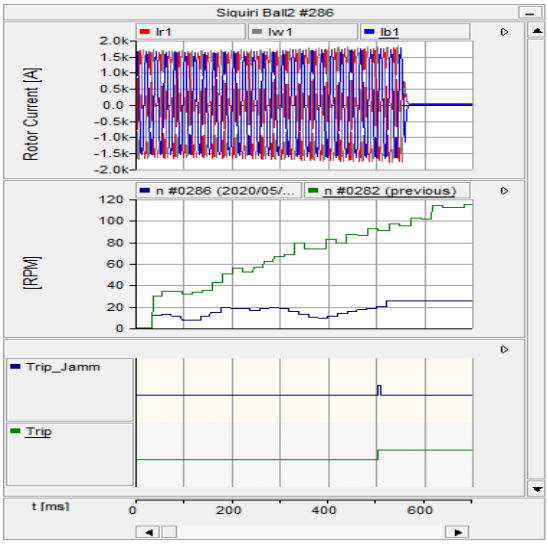
SDG presented a paper on this protection at the 2011 SAG conference in Vancouver, Canada, and it has been running reliably on large LRS-stared mills since 2010.



Mill Jammed

While a locked rotor is no problem on a squirrel cage motor, it has associated complications on a wound rotor induction motor, especially if driving a grinding mill. A locked rotor condition has been found more commonly at Mill Safe Start sites than would have been suspected, due to problems with barring/inching gear interlocks or main gear problems. Without the Mill Jammed protection, the LRS dippers continues to move down, increasing torque, and the stator side protection trips only by the time it reaches a high enough current to trip on overload. This is extremely undesirable and leads for example to barring/inching motors exploding, pitted slip-rings which causes excessive brush wear leading to slip-ring flashing, or broken mechanical couplings or gears.

The Mill Safe Start "Mill Jammed" element measures the motor speed by means of the rotor current frequency, and implements a Mill Jammed protection that trips the mill immediately if the mill does not speed up within a short time after application of power.

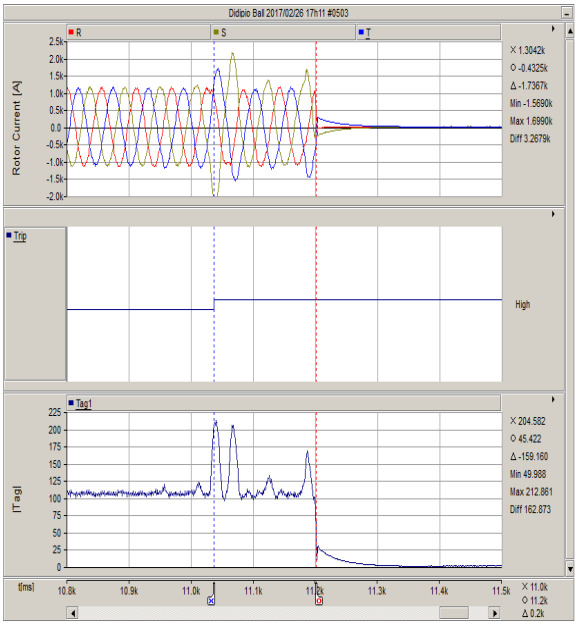


I>> (LRS Flash)

Typical conditions that were encountered and recorded at MSS sites in the field include:

- Arcing between the live bars and the LRS metalwork.
- Arcing between the conductors and the water. (Horizontal movement LRS)
- Leaks in the isolating pipes taking the busbars through the water to the bottom electrodes, creating currents spikes as the current takes a shortcut directly from the busbar to the top electrodes. (EPM type LRS)
- Arcing directly through the vapour between top and bottom electrodes, in cases of serious boiling and current run-away in the "critical area" just before the top and bottom electrodes merges. (EPM type LRS)

The graph illustrates a typical LRS Flash condition, in this case intermittent arcing. The trip was issued instantaneously when the |Tag| breached the 200% trip level. This illustrates a level of sensitivity and speed not obtained with conventional protection.



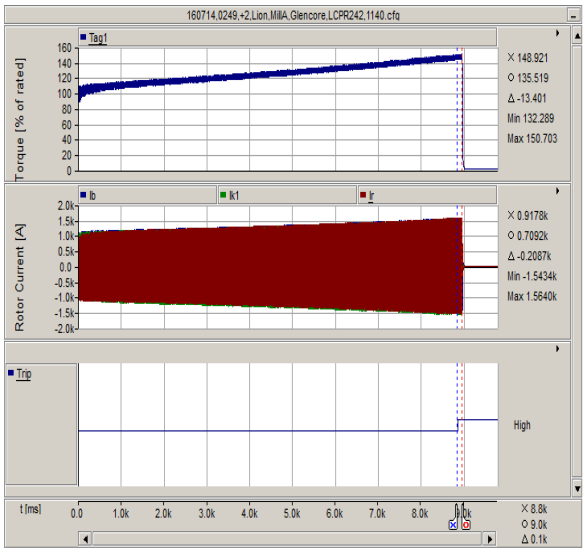
I>> (Over Torque)

The I>> is also triggered when a rotor current threshold is immediately exceeded at energization, or else slowly exceeded by ramping up. Typical conditions that has been encountered at MSS sites in the field where this protection will trip are:

- LRS dipper position not at top/start position when motor energized.
- LRS dippers move down too quickly.
- Electrolyte concentration too high.
- Electrolyte too hot.

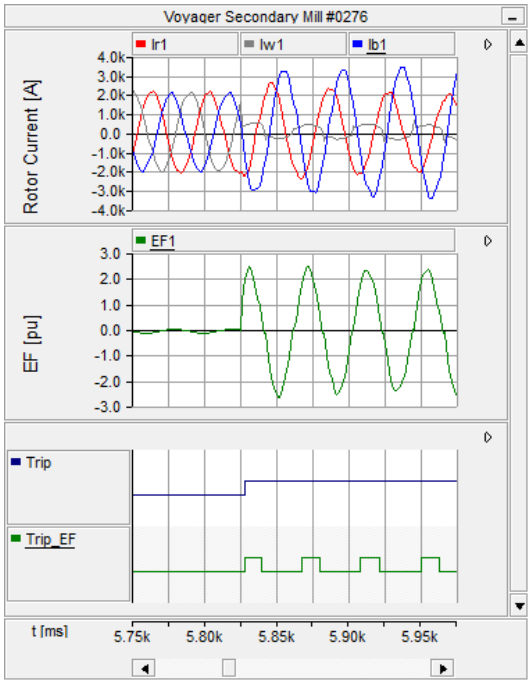
Figure 2 illustrates an OverTorque trip, in this case a mill jammed condition tripped on by a Generation I Mill Safe Start that was not equipped with the Mill Jam protection.

The LRS moved down with the mill jammed, and was tripped when the torque reached the setting of 150%, preventing mechanical damage in this case. (The Jamm element would have tripped in 0.5s)



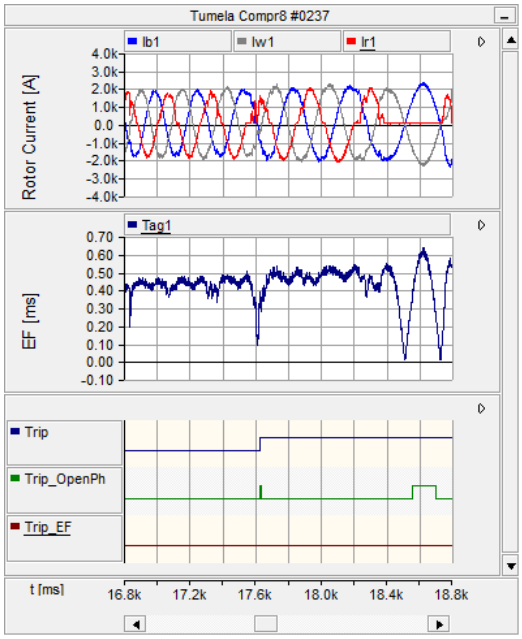
Earth Fault Element

- The probability of a flash in the slip ring compartment to earth is highest soon after start-up, as the rotor voltage is the highest at the start.
- However, the fault current is limited by the liquid resistance starter, an earth fault bypass only one of the three resistor elements in the LRS.
- If the motor is tripped before the earth fault develops into a phase-to-phase fault, damage is limited and the motor can likely be repaired in situ.
- Due to the low current, this fault is not normally detected by the motor protection relay on the motor stator. However, the ALRS/MSS detects it within milliseconds and issues a trip in time to limit damage.
- If it is not detected and tripped in time, it will develop into a violent three phase fault, and the motor will have to be swopped out due to extensive damage to the slip-rings.
- (If the earth fault is deeper into the motor rotor winding, the earth fault may likely occur later in the start-up, due to high speed. This is of course not as easy to repair as a flash inside the slip-ring compartment.)



Open Phase Element

- The trace above shows the brushing failing on the blue phase slip-ring 17.5s from start-up.
- The open phase element detects the loss of phase in milliseconds and issues a trip.
- It is possible to be this fast and yet remain secure by looking for the condition where one phase is open circuit while the other two mirrors each other around zero, still obeying Kirchhoff.
- At this point there has not been any earth fault and the damage is limited.
- Typically only the slip-rings need to be polished, and the brushes serviced or replaced.
- However if this is not detected and tripped in time, the brush problem leads to a phase to earth fault, because there is high voltage present on the slip-rings during start-up.



Brush Element

- Once the motor is running at full speed, another element is used to detect brushing failure on the very low frequency steady state rotor current.
- After start-up the brushing normally fails slowly and can run a long time (many hours) in this partially failed state, as there is not much voltage on the slip-rings to drive a flash to earth.
- However, the longer the motor runs like this, the more damage is done to the slip-rings.
- The Brush element picks up the partial failure before the OpenPh element would, and is only used after start-up during running of the motor.
- During slow brush failure, the two healthy phases morph towards block waves, compensating for the failing phase and therefore the OpenPh element is not effective in this case.
- With the Brushing element an alarm level can also be set before the trip level is reached.