Saving energy

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Wound rotor induction motors (WRIM) have been popular for decades in the cement and mining industry for starting and driving large grinding mills. In fact, until about 1985, a wound rotor induction motor was the only large ac motor that controlled starting characteristics and adjustable speed capability.

A WRIM is a type of induction motor with unique construction. Its three-phase stator is typical of any induction machine and is usually connected directly to the power system, usually a medium voltage source such as 2.3kV, 4.16kV, or 6.6kV. The rotor also has a three-phase winding, usually connected in a wye (or star) circuit. The three terminals of the rotor winding are connected to separate slip rings. Brushes ride on these slip rings and the rotor winding is connected to an external liquid rheostat or resistor bank. This resistance, when inserted into the rotor circuit, adds to the rotor resistance and reduces starting currents.

The motor speed can be adjusted by changing the resistance. The continuous power flowing into the resistor is lost as heat. Adding resistance to the rotor circuit also changes the speed at which maximum torque occurs for the motor, so high torques can be produced at low speed for starting loads with high breakaway torque requirements.

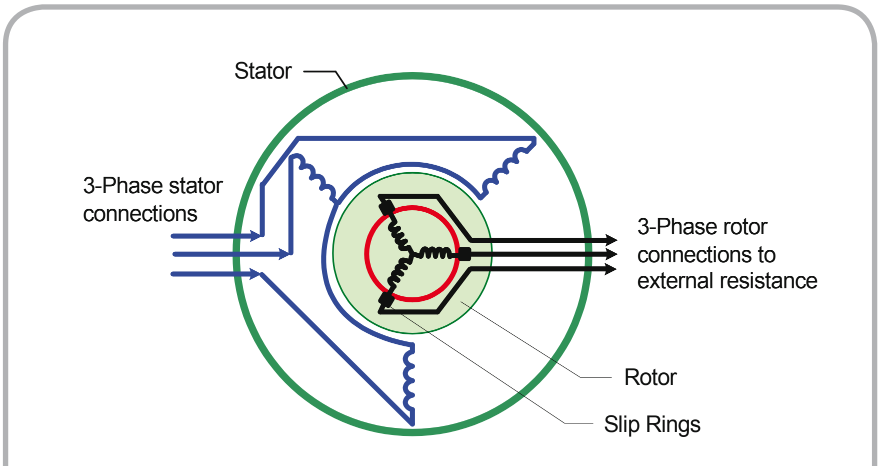

Figure 1: wound rotor induction motor

Slip power recovery systems

The slip power recovery (SPR) drive is an external system connected to the rotor circuit in place of the external resistors. The SPR provides speed and torque control like the resistors but can also recover the power taken off the rotor and feed it back into the power system to avoid energy waste. In usual practice, an SPR drive consists of two interconnected power converters as shown in Figure 2. The rotor converter is connected to the three-phase rotor winding. The feedback power converter is connected to the power system, usually through a transformer that matches the output voltage of the converter to the power system. The regenerative or feedback power converter is controlled to modulate the amount of power put back into the power system, allowing control of the motor speed. All the rotor energy previously lost as heat in the rheostat is now saved, and for large motors, this amounts to significant cost savings.

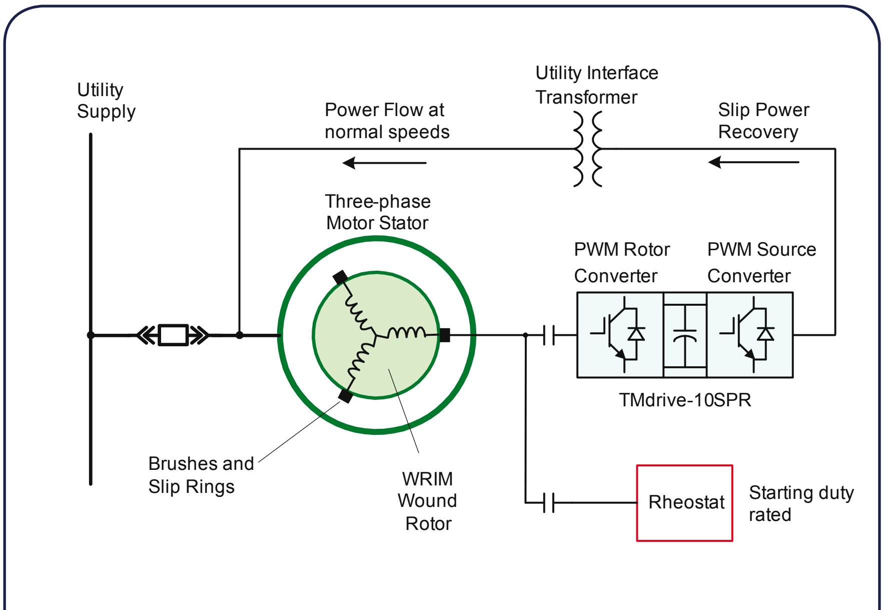

Figure 2: wound rotor motor with slip power recovery

When are Wound rotor motors used?

Some demanding applications that favour the use of a WRIM over a standard induction motor or synchronous motor are listed below:

- Grinding mills that require high torque at starting as they often sit with a full load of rocks. The WRIM is used here because the rheostat provides an inexpensive way of starting the loaded motor
- Mills that require variable speed operation

• Plants that have a weak power system because of a long supply line or minimally sized local generator. This makes it hard or impossible to start large motors, particularly those which must start under load.

Mill drive example

An example of slip power recovery is the wound rotor motor shown below, one of two for powering a new 10,000 kW SAG mill in Australia as shown in Figure 3. This installation includes:

- Two 5000kW six-pole WRIMs with 11,000v stators
- A combining gear box driving the mill
- One 10,000kW liquid resistance starter (rheostat)
- One dual Slip Energy Recovery system (SPR drive).

PWM SPR equipment

An example of a SPR drive and control cabinet line up is shown in Figure 5. This system includes a TMEIC TMdrive-10SPR 460/690 volt AC drive that controls the rotor circuit.

WRIM SPR system

The WRIM SPR drive system is part of a more a complete package that coordinates starting the motor and making it available to the process control for speed control. The starting means can be either a contactor/resistor arrangement or liquid rheostat system, depending on customer preference and load torque starting requirements. This complete system integrates the starting and speed control functions into one drive system. On the other hand, it is also possible to retrofit the SPR drive system to an existing motor and retain the existing starting means. The level of coordination between the SPR and the starting means is determined on a project by project basis.

Figure 3: one of two wound rotor motors for a 10,000kW SAG mill

PWM SPR drive advantages over previous WRIM systems

Good power factor at utility

Low power factor operation characterised previous thyristor based SPR systems. In the PWM SPR system the converter operates at unity power factor at all times. This converter is similar to those used in regenerative squirrel cage induction motor drives. As a bonus, any excess capacity built in to the source converter can be used to correct other lagging power factor loads on the system.

Figure 4: typical SAG mill

Low harmonics at utility

Previous thyristor based systems injected significant harmonic currents into the utility system. In contrast, the PWM SPR converter is switched at a higher frequency (usually 1500Hz or higher). The harmonic currents from this type of converter are centered around the switching frequency and multiples of it. These currents are greatly reduced by the impedance (15-20 per cent on the drive rating base) in the source reactor. If a harmonic study reveals that the additional filtering is needed, a simple high pass filter can reduce the remaining high frequency harmonics. This type of filter is not sensitive to changes in the power system because it is closely connected to the PWM converter, so future changes are not likely to disturb it. The PWM converter needs no reactive power support, so the filter is not sized to provide that.

No motor torque pulsations

Unlike other WRIM controls, a PWM SPR drive does not create torque pulsations in the motor. The PWM converter provides very smooth rotor current control, so the torque output from the motor has very low ripple. As a result, there are no requirements for special damped couplings or banned speeds due to mechanical resonance.

Controlled speed range

The controlled speed range the low voltage PWM drive can provide is typically from 70-100 per cent of rated speed. The lower speed range is set by the point where the rotor volts fall below the typical 690 volt rating of the converter. Additionally, since the PWM converter connected to the rotor can create a voltage of desired frequency and magnitude, the speed can be varied smoothly. The motor can be run very close to synchronous speed, even above synchronous speed if the motor and mechanical load will allow this.

Modern technology

The PWM SPR drive is based on state-of-the-art, proven low voltage induction motor drive equipment. Since such drives are in volume production at this time, support should be available for years to come. Getting renewal parts for older thyristor based SPR drive products can be very difficult, especially if the need is for electronic parts.

Power savings

The example below compares three possible arrangements for variable speed operation of a 5000kW motor. The first case is a WRIM using a rheostat for starting and speed control, the second is an induction motor (or WRIM with shorted rings) driven by a medium voltage variable speed drive, and the third is a WRIM with speed controlled by a relatively small low voltage SPR drive. In the induction motor system, all the motor power passes through the MV drive. With the SPR drive system, only a fraction of the motor power passes through the SPR, so it is a smaller and less expensive LV drive. With the induction motor and variable speed drive, the motor can be smoothly started but the drive is a significant cost adder. Also there is no backup starter if the drive fails; but with the WRIM the rheostat is available to start the motor.

Figure 5: an example SPR drive system lineup

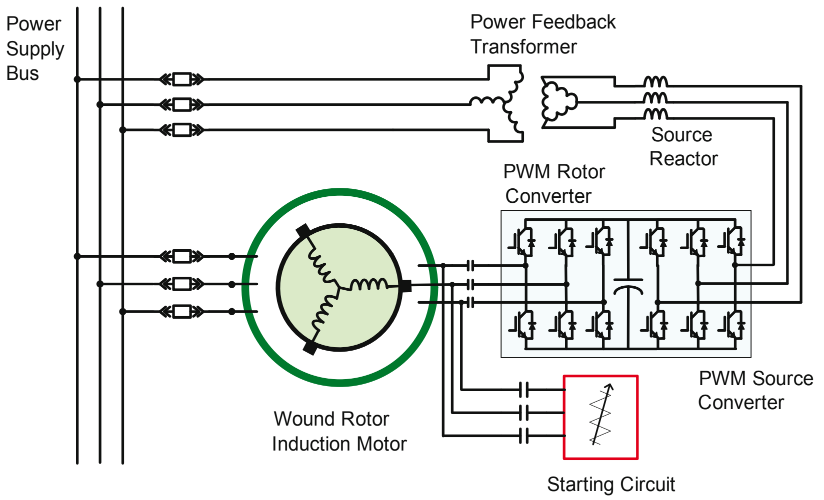

Figure 6: details of PWM drive providing SPR

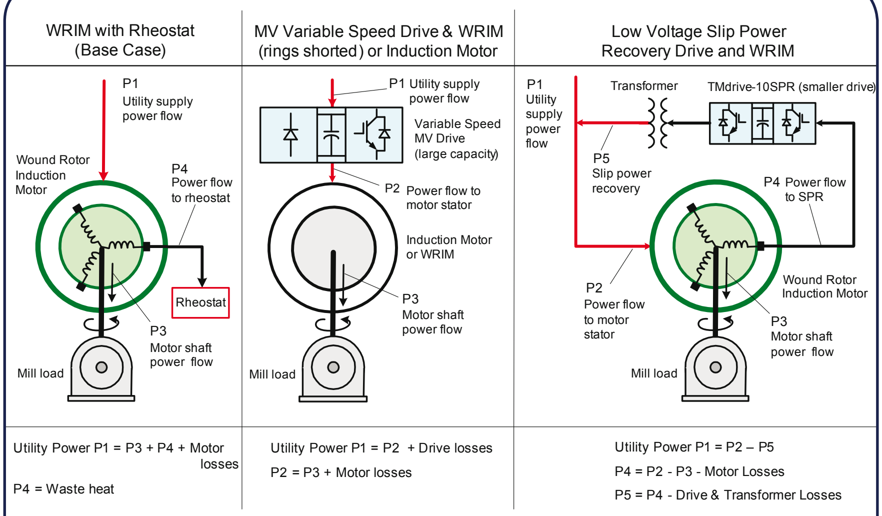

Figure 7: comparison of three possible arrangements for variable speed mill operation

Energy consumption

In Case 1 of Table 1, for the given load at reduced speed, the WRIM with rheostat uses the most power (P1) because of heat wasted in the variable resistance. For Cases 2 and 3, the energy savings relative to the WRIM case are calculated in the table.

For a mill motor rated at 5000kW, running at 80 per cent speed, the power saving using the SPR drive, Case 3, is 970kW. Assuming two motors as in the 10,000kW mill example, and an electricity cost of 7¢/kWh, the annual savings are US$1,189,600. The savings with the MV PWM stator drive are a little less than the SPR case. Note that the lost, or recovered, slip power is Slip X Rated Power, so at lower speeds the savings are even higher.

Economic and other comparison factors

In comparing various motors and speed control systems, factors such as the initial equipment costs and level of maintenance required should also be considered. Table 2 highlights such factors. The motors discussed can be new or existing motors.

Table 1: energy consumption calculations

Power flow for constant load torque conditions	*Power flow*	*Case 1 WRIM with Rheostat*	*Case 2 Variable speed MV drive & WRIM (rings shorted) or induction motor*	*Case 3 Slip power recovery drive and WRIM*
Mill load at full speed, shaft kW	–	5000kW	5000kW	5000kW
Mill load at 80% Speed, shaft kW	P3	4000kW	4000kW	4000kW
Utility supply power flow	P1	5263kW	4340kW	4293kW
Power flow to motor stator	P2	5263kW	4210kW	5263kW
Power flow to slip drive or rheostat	P4	1000kW	–	1000kW
Slip power recovery after transformer	P5	–	–	970kW
Power savings relative to Rheostat control, difference in utility power flows P1	–	–	923	970kW
Cost savings per year with 7¢/kWH electrical power (24 x 7 x 365)	-	-	US$566,000	US$594,800

Various advantages

In addition to energy savings, lower cost, and simple starting device, the SPR drive system has other advantages over a high power medium voltage variable speed drive (VSD):

- There is inherent fault tolerance since it is possible to operate the motor even if the drive is faulted
- Smaller footprint than a MV PWM variable speed drive
- Can work with any stator rated voltage.
- For constant torque loads it is possible to get more horsepower out of the same motor by running at speeds over 100 per cent. This requires the SPR drive to put power into the rotor, and assumes the motor is rated for higher speed
- The SPR drive can provide additional reactive power (VAR) compensation.

Conclusion

In addition to numerous large WRIM motors on grinding mills, slip power recovery drives have been applied in other industries, such as in municipal water plants (pumping), and in paper plants (induced draft fans). Many of the SPR installations have been retrofits to existing controls for large WRIMs, that use rheostats for speed control. In these upgrades the rheostats are often kept for motor starting.

Experience in all these industries shows the new SPR system, as well as providing the required high starting torque, has many advantages including energy savings, effective adjustable speed operation and high reliability.

Table 2: comparison of various motors and speed control systems

	Motor and speed control options			
Comparison factors	*WRIM with Rheostat*	*New induction motor with MV Variable frequency stator drive*	*Existing WRIM (rings shorted) with MV Variable frequency stator drive*	*SPR Drive*
Initial cost of drive and controls	Moderate	High	High	Moderate
Cost of new motor	High	Moderate	Existing	High (new) or existing
Energy losses/waste heat	High	Low	Low	Lowest
Maintenance required	Moderate	Low	Low	Low
Starting torque	High	High	High	High
Starting device/backup	Rheostat	No backup	Rheostat	Rheostat