

# Electric Motors for Elevators

by David Herres

## Learning Objectives

After reading this article, you should have learned:

- ◆ How DC motors work.
- ◆ How synchronous motors work.
- ◆ How induction motors work.
- ◆ How the speed of an AC motor is controlled.
- ◆ How to troubleshoot a variable-frequency drive (VFD).

The first motors operated on DC. In fact, the invention of a practical DC motor long preceded Nikola Tesla's insight that AC would offer substantial benefits. Thomas Edison and his associates clung to the idea that DC was more practical, but history favored Tesla and George Westinghouse, at least in regard to the war of currents, as it became known. Before that issue was resolved, DC motors for elevator usage had become the industry standard and would remain so for quite some time.

To begin, we'll look at the basic requirements for electric motors to work. Most electric motors convert electrical energy into rotary motion. (There is such a thing as a lineal actuator, but that is not our focus for now). Rotary motors consist of a rotor attached to a shaft supported by two bearings so it is free to turn, and a stator that, as its name suggests, is stationary. It is mounted on the inside of the motor housing.

A pulley, gear, saw blade, grinding wheel or other tool may be attached to the rotor shaft so useful work is performed. In order to turn, the rotor, in conjunction with the stator, makes

use of the relationship of electricity and magnetism, first noted by Hans Christian Ørsted in 1820 when he observed that the needle of a compass deflected when positioned near a current carrying conductor. In 1831 Michael Faraday in the U.K. and Joseph Henry in the United States independently described the phenomena in greater detail, and later in the century, James Clerk Maxwell provided an extensive mathematical analysis. Prior to these 19th-century developments, electricity and magnetism were seen as unrelated phenomena. Now that the relationship was clear, researchers and inventors sought ways to exploit this new knowledge. Previously, simple DC motors, powered by chemical batteries, had been built. However, they were not powerful and were unable to perform useful work.

The rotor of a DC motor can be made to turn, but only if there is commutation. If a steady DC voltage is applied to windings in both the rotor and the stator, the shaft will rotate at best a part turn, until the opposing poles are at their closest, whereupon further rotation will not take place. For the shaft to turn on a continuous basis, polarity of the electrical current in either the stator or the rotor must be switched so the magnetic field is periodically reversed, causing the more distant poles to attract. In this way, the rotor is always chasing after the stator. As the poles get close, the polarity reverses so the rotary motion is ongoing. This switching takes place either internally or externally and is known as commutation. A skilled operator could work a switch, configured as a push button, and pulse the current so

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as to make the rotor turn. However, for a practical motor, commutation has to be automatic.

A further issue is that wires cannot be directly connected to the terminals of the rotor-mounted windings, because they would quickly twist and break. These two requirements are met by having a commutator affixed to the rotor. Stationary copper brushes (now replaced by carbon bars that are still called brushes) contact the turning commutator segments, insulated from one another, providing the switching mechanism necessary for continuous rotation, which gets the current into the rotor. As in any motor, the energy has to get into the rotor and there has to be switching for the rotation to take place.

Rather than having windings in both rotor and stator, one of these can be replaced by permanent magnets (PMs). These are often powerful, rare earth magnets epoxied to the inside of the motor housing. The static PM fields interact with the commutated electromagnetic field associated with the rotor and the shaft is made to rotate. Various schemes have been proposed where PMs in both rotor and stator would comprise a functioning rotary perpetual motion machine. The problem with this arrangement is that in order for it to work there would have to be commutation. One set of PMs would have to switch polarity at the correct intervals. The way to do this would be by mechanically flipping over the magnets, but this would take more energy than the output of the motor. Another way for a motor to work, requires new energy on an ongoing basis, which must be fed into either the rotor and/or the stator.

DC motors have two important characteristics, which account for the fact that they have persisted in elevator applications even in an AC-powered world. The first of these characteristics is that the speed of a DC motor can

be controlled by varying the voltage. As an elevator car approaches its destination, it slows down as opposed to continuing full speed until the floor of the car is even with the building floor, then stopping abruptly. This would be uncomfortable for passengers and hard on the machinery.

It is not practical to vary the speed of an AC motor by varying the voltage. The speed of a synchronous or asynchronous (induction) AC motor is frequency dependent. One can slow an AC motor by reducing the voltage so that the motor begins to stall out, but it is not a good way to vary the speed. Some AC motors have two speeds. They have separate windings for the two speeds, with one wire for each speed and a common return wire.

Similarly, DC motors can be reversed by switching polarity of the electrical supply, but this cannot be done with a single-phase AC motor since the polarity is constantly being switched. Three-phase motors can be reversed

by switching any two of the three phases.

Though DC motors have advantages such as smooth speed control and simple reversibility among them, they require somewhat more maintenance because the electro-mechanical brush-commutator ensemble experiences continuous wear. If brushes are not replaced in a timely fashion, prior to failure, sparking occurs and the commutator will be damaged. This involves a more costly repair than merely changing the brushes. Additionally, brushes generate dust and heat within the motor, presenting potential fire hazards. There is also radio frequency interference that may affect the operation of electronic equipment. Brushless DC motors do not have these disadvantages. They are capable of variable speed operation by means of an electronic controller. They are seen in computer disc drives and motion control applications in machine tools.

To generalize, DC motors, while conceptually simple and capable of



Otis DC elevator motors

quality operation, are more complicated mechanically and require increased maintenance, so they are more expensive to run. This view is not the whole story, however. If we are talking about an elevator rebuild, it may or may not be appropriate to replace a functioning DC motor, depending on the extent to which the project is capitalized. The decision should be made with great care, considering both initial cost and long-term benefit of using AC.

Turning to AC motor technology, we'll look at it from an electrical and mechanical point of view. As mentioned, electrical power was for many years exclusively DC. A great many individuals participated in the conception and development of the AC grid. Tesla became the central figure in the ascendancy of AC. Through his efforts, in conjunction with Westinghouse, AC was eclipsing DC, but real progress had to wait for the development of an AC motor. Undoubtedly,

there were early attempts to power a DC motor with AC. It became apparent that a different machine would be needed.

DC motors are able to rotate because the electricity fed into the rotor windings is commutated or switched. For an AC motor, the switching already exists in the electrical supply, so it may be said to be externally commutated. AC motors may be synchronous or asynchronous (induction). In both cases, the AC from the power supply is fed directly into the stator windings. Because of the cyclic nature of this power, a rotating magnetic field is established. If the motor is more than 5 hp, as generally the case for elevators, the stator receives three-phase power. Three separate circuits with wires in common, 120° out of phase, are derived from the utility supply or on-site generator by means of delta- or Y-connected windings. Three wires carry this power into the motor housing and connect to evenly-

spaced coils so that the three magnetic fields rotate in concert. All three-phase AC motors have this in common, and single-phase AC motors have one rotating magnetic field. Beyond this, not all AC motors work the same. Where they differ is in how the rotor is powered.

A wound-rotor synchronous motor is equipped with a system of slip rings and brushes. The slip rings are attached to the rotor shaft, and the stationary brushes contact them and are wired to the external supply. This arrangement is more trouble-free than the DC brush-commutator combination. Since the slip rings, unlike the commutator, are not segmented, there is less wear on the brushes. Moreover, less current is carried, just enough to power the rotor.

Additionally, there are non-excited synchronous motors that use other means for enabling the rotor to interact with the stator. In these motors, the rotor is made of solid steel. The stator's rotating magnetic field magnetizes the rotor and at synchronous speeds the two magnetic fields rotate together so that the shaft turns and useful work is performed. There are three types of non-excited synchronous motors, each with a different method for enabling the rotor to follow the stator's rotating magnetic field:

- ◆ Reluctance motor: The steel rotor has salients, or toothed poles that project outward so they are near the stator, with enough clearance so they do not rub even as the bearings begin to wear. There are the same number of these projections as there are poles in the stator. At synchronous speed, the motion of the rotor is locked to the rotating magnetic stator field. However, this type of motor will not start on its own, so the squirrel-cage rotor has supplementary windings embedded in the steel body. The reluctance motor starts as an induction machine until it



MCE's iControl AC elevator controller with user interface having diagnostic capability

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approaches synchronous speed, whereupon it shifts into its primary mode. At synchronous speed, mutual inductance between stator and rotor ceases.

- ◆ Hysteresis motor: Rather than having salients or projecting teeth as in the reluctance motor, the hysteresis motor has a uniform cylindrical steel rotor. All parts of the stator are magnetized and follow the rotating magnetic field of the stator. When the rotor speed catches up with the speed of the stator's rotating magnetic field, lockup occurs and the motor enters the synchronous mode. This type of motor is self-starting and does not require an induction winding, although it may be provided to give extra starting torque in applications where it is needed.
- ◆ PMS: PMS are embedded in the rotor to provide lockup at synchronous speeds. However, these motors are not self-starting and the stator must be powered by a variable frequency drive (VFD) to facilitate overcoming the rotor's inertia of rest.

Small synchronous motors will start on their own because there is not too much inertia of rest on the part of the rotor. In sizes more than 1 hp, many synchronous motors are DC-excited. This electrical energy is supplied from an outside source through slip rings.

Synchronous motors in small sizes are used where precise timing is required, as in wall clocks and timers. The utility keeps close watch on its frequency, and if over a period of time a few cycles are lost, they will momentarily accelerate the generator in order to compensate, so over a period of time clocks and timers will remain accurate. In large sizes, synchronous motors have the advantage of enhanced efficiency in addition to accurate speed control. Moreover, they have good power factor correc-

tion capability, compensating for the heavily inductive loads in industrial facilities.

The other broad category of AC motors consists of asynchronous machines. They are known as induction motors on account of the way in which electrical energy is imported into the rotor. The speed of rotation is not locked to the power supply frequency, but it is highly frequency dependent, always a specified percentage of it slower but, of course, never faster.

Despite the advantages of the synchronous motor, the induction motor is more widely used, because it is simple, economical and relatively maintenance free. More than 100 years after his time, Tesla's presence is in the world of AC motors, where perhaps 90% of them are induction machines.

We have seen the synchronous motor can turn because of the interaction between stator and rotor magnetic fields. The induction motor works in the same way. The only difference is in how the electrical energy gets into the rotor. In the induction motor, the stator is in effect the primary of a transformer and the rotor is the secondary, so there is no need for brushes or slip rings, much less a commutator.

Once the electrical energy gets into the rotor, a magnetic field is established and the rotor starts chasing after the stator's ever-elusive magnetic field. In fact, it never catches up because if the two speeds were to lock up and become synchronous, mutual inductance would cease. For there to be the mutual inductance that is characteristic of an AC transformer, the two magnetic fields must be moving relative to one another, and before they could synchronize, the inductive coupling would disappear. For this reason, the rotor always turns a certain percent slower than the stator's rotating magnetic field. It is to be emphasized that the rotor's

lack of synchronization is not merely a phase lag as in reactive wave forms, but it consists of an actual reduction in rpm, so the loss of cycles is cumulative and becomes greater with the passage of time. Therefore, induction motors are not suitable for clock and timer applications. The amount of the reduction in speed is called "slip" and is expressed as a percentage. Slip must be seen not as some sort of wasted or lost energy but as an essential component of the induction motor's normal operation. Naturally, the amount of slip increases as the motor is more heavily loaded. Due to the greater difference in speeds, there is greater inductive coupling and the current in the rotor windings increases. The bottom line is that with increased load the motor's torque increases.

Prior to arrival on the scene of the variable-speed drive, it was difficult to control the speed of the induction motor. For powering elevators, the smooth running DC motor filled the need for many years.

The second half of the 20th century saw vast innovation and growth in the field of power electronics. Earlier, solid-state semiconductors had replaced vacuum tubes in most audio and video applications. Over a few decades, solid-state technology moved into more powerful applications and concurrently everything went digital.

Previously, practical means for precisely and reliably controlling the speed of AC motors were not available. With the development of the VFD, elevator motor technology abruptly changed. (Adjustable speed drive, adjustable frequency drive, variable speed drive and variable-frequency drive are all roughly equivalent terms. The only difference is if it contains the word "speed," it can refer to hydraulic or other non-electrical systems. The VFD is most precise.)

A VFD makes possible precise control of AC motor speed, allowing the motor to run over or under name-

plate speed, subject to limitations. Ordinarily, reducing the supply voltage for an AC motor will reduce its speed only because it is being loaded more heavily. The result will be loss of efficiency, an increase in temperature and shortened motor life.

The VFD controls the speed of an AC motor by altering the frequency of its power supply. As we have seen, the speed of both synchronous and asynchronous motors is frequency dependent. The magnetic field associated with the stator turns at a speed that depends upon the frequency of the power fed into it and motor rpm conforms to it as well. Varying the frequency of the motor's power supply is a simple and effective way to control the speed of the motor. The speed can be reduced without causing the motor to overheat except in the sense that if there is a fan attached to the shaft, it will turn slower at reduced motor speed, resulting in less air cooling. For this and other reasons, even though any AC motor, synchronous or induction, can be controlled by a VFD, some motors are not suitable. Before pairing a VFD and motor, some research is in order.

For VFD use, a synchronous motor can make a premium installation. However, since exact synchronization is not essential for an elevator motor, the majority of new construction and DC motor replacements involve induction motors.

The typical VFD for an AC elevator motor is fairly simple, user-friendly and trouble free. There is a three-phase input that may be identified, if it is not labeled, by the fact that it is in a large raceway coming from the motor disconnect. Additionally, there is a small control wire coming from the speed control potentiometer, typically carrying a signal ranging up to 10 V DC. This is connected to the elevator motion controller and permits reduced speed for leveling at each landing and running in the inspection mode.

There is another control loop for reversing motor rotation, this also in response to directions from the elevator control panel.

On the front panel of the VFD, there will be a user interface with alphanumeric display. Additionally, there will be lights labeled Run, Stop, Reverse and Fault to indicate system status. At the VFD output there will be a three-phase feed to the motor. It conveys nameplate voltage to the motor, but rather than the 50 or 60 Hz frequency supplied by the utility, the frequency varies as needed to control the speed of the motor. A normally-open Start button and a normally-closed Stop button on the outside of the cabinet provide manual override capability. Running from the motor back to the VFD are fairly light conductors that provide a feedback signal from a tachometer connected to the motor.

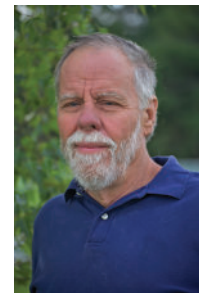
Troubleshooting and repair of the system is straightforward. Check input and output power at the VFD, watching particularly for a dropped phase. Check the control voltages. If these are all normal but the motor is not turning, there is a problem with the motor or the load has become locked up, often resulting in immediate over-current device tripping.

If the VFD has good input voltages but no output, the fault is internal. Before opening the cabinet, remember the large power supply capacitors are capable of holding a lethal charge long after the equipment has been disconnected from its power supply. To bleed off these charges, do not short out the capacitors. Instead, connect a low-impedance load across each set of terminals.

Examine the VFD electronics to see if there is a burnt wire or component. If not, there is a good chance one of the full-wave bridge rectifier diodes has gone bad with no visible indication. They can be checked with a multimeter in the ohms mode to see

if they will forward and reverse bias as the meter connections are switched. Often a faulted diode will read open both ways.

The documentation that came with the VFD should include a schematic. Oscilloscope readings should pin down the faulted component, and this approach is much better than trial and error replacement of circuit boards, which is a costly procedure and may not get to the root of the problem.



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written for such publications as *Electrical Construction and Maintenance*, *Cabling Business Magazine*, *Electrical Contracting Products*, *Electrical Business and Engineering News Record* since 2006. He holds a BA in English Literature and Composition from Hobart College of Geneva, New York, but has focused exclusively on electrical work in New Hampshire since 2000.

### Learning-Reinforcement Questions

Use the below learning-reinforcement questions to study for the Continuing Education Assessment Exam available online at [www.elevatorbooks.com](http://www.elevatorbooks.com) or on page 103 of this issue.

- ◆ What are the requirements for any rotary motor to function?
- ◆ What two parts do all rotary motors have in common?
- ◆ Why does a DC motor require a commutator?
- ◆ What determines the speed of a synchronous motor?
- ◆ Why does an induction motor have no brushes?



## ELEVATOR WORLD Continuing Education Assessment Examination Questions

### Instructions:

- ◆ Read the article “**Electric Motors for Elevators**” by David Herres (page 73) and study the learning-reinforcement questions at the end of the article.
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1. The first elevators powered by electricity had:
  - a. DC motors.
  - b. Synchronous motors.
  - c. Induction motors.
  - d. Variable-frequency drives (VFDs).
2. A DC motor is able to turn, because switching takes place:
  - a. Outside the motor.
  - b. In the stator.
  - c. Between the brushes and the commutator.
  - d. None of the above.
3. The speed of a DC motor can be changed by varying:
  - a. The frequency.
  - b. The voltage.
  - c. The polarity.
  - d. None of the above.
4. A synchronous motor rotates faster:
  - a. When powered by DC.
  - b. When provided with a commutator.
  - c. When the frequency of the power supply is lowered.
  - d. When the frequency of the power supply is raised.
5. Synchronous motors have:
  - a. Poor power factor.
  - b. Good power factor.
  - c. No effect on power factor.
  - d. Internal commutation.
6. Induction motors:
  - a. Require brushes to function.
  - b. Are more expensive than synchronous motors.
  - c. Rotate faster than synchronous motors.
  - d. Are also known as asynchronous motors.
7. Induction motors work on the principle of a transformer.
  - a. True.
  - b. False.
8. VFDs are:
  - a. Obsolete in today's digital environment.
  - b. Used in conjunction with DC motors.
  - c. May power either induction or synchronous motors.
  - d. Are too expensive for most elevator applications.
9. VFDs may contain hazardous voltages even after they are powered down.
  - a. True.
  - b. False.
10. To troubleshoot a VFD, begin by:
  - a. Measuring input, output and control voltages.
  - b. Powering down the chassis.
  - c. Shorting out the capacitors.
  - d. Taking oscilloscope readings of the input voltages.

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