# Regenerative Elevator Drives: What, How and Why

*by Donald Vollrath, Magnetek, Inc.*

**Learning Objectives**
After reading this article, you should have learned about:

- How mechanical and electrical power are related
- How the cycling of an elevator affects the flow of energy
- How various motors and drives react to bidirectional energy flow
- How regeneration can lower energy costs
- Why safety concerns of regeneration need to be dispelled

Various forms of elevators have been with us for several hundred years. At first, they were crane-like mechanical lifts with drum-and-winch mechanisms powered by humans, draft animals, water wheels or steam. Block-and-tackle roping allowed even the heaviest loads to be lifted.

For repeated use, inventers quickly learned to counterbalance the weight of the lifting platform or car cage in order to reduce the effort required to move expected payloads up and down the hoistway. Many improvements toward elevator safety and practical electric motors were invented near the end of the 19th century. Despite scientific disputes about AC versus DC electric power distribution, almost all elevators were converted and built to be powered by electric motors by the 1920s. Drum-and-winch operation gave way to counterweighted systems with direct traction sheaves on steel suspension ropes.

The electric-powered elevator became a catalyst, allowing a boom of tall-building construction in large cities. Despite many improvements toward safety and ease of use, the elevators of today still use the same counterweighted lifting mechanism and a traction sheave on the suspension ropes for the simple reason that counterbalancing the weight (mass) of the car against gravity reduces the amount of force required to move the car up and down the hoistway. Also, when additional counterweight is added to balance the system with an average payload, the least amount of effort is required for the expected range of typical loads.

Less effort to move an average load also means less average energy consumption. In today's world, energy conservation is one of the major goals for improvement. We typically pay for energy as measured by the kilowatt-hour utility meter. Whatever we can do to conserve and minimize energy use will certainly help save money and conserve energy supplies.

While it is recognized that many short-rise buildings use hydraulic lifting mechanisms to operate an elevator, the illustrative discussion within this article pertains only to traction elevators.

## Energy

What is this thing we call energy? From a scientific point of view, energy is the act of doing work, in which the basic definition is a force multiplied by the distance an object is moved. There are two major forms of mechanical energy involved when operating elevators: potential and kinetic energy.

Potential energy is gained or lost by an object (mass) as it is raised or

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lowered against the force of gravity. An elevator must put energy into the mass of the payload when it is lifted (weight X distance). That same amount of potential energy will come out of the payload when it is lowered by gravity.

Kinetic energy is the energy of motion stored within a mass as it is moving. We often refer to this as inertia or momentum. The magnitude of kinetic energy in a moving object is equal to one-half the mass X the square of velocity. It must be added to any object in order to make it accelerate or move. Likewise, that same amount of kinetic energy must be removed from the mass to make it stop. Kinetic energy becomes important when we consider how elevators are constructed and how fast they are moving.

All of the major parts of an elevator must move in order to move the payload. The need for mechanical strength dictates that the car frame and counterweight have significantly more mass than the payload rating of the elevator. As a result, the total kinetic energy added to accelerate and then removed to decelerate the elevator apparatus is four to five times what it would be if only the payload were moved. Note that energy flow being discussed is mechanical and bidirectional. That is, we must put energy into the mechanical parts and payload to make it accelerate and rise. Energy comes out again when we stop the motion or lower the load. With an elevator, this action repeatedly occurs many times during the day. The cyclic nature of energy flow yields an ideal opportunity to minimize the overall consumption.

The rate at which energy flows to accomplish work is called power, or force times speed in mechanical units. The electrical units are watts (or kilowatts), which is voltage (the force) multiplied by amperes (the rate or speed of electron flow) that occurs at the same time. The flow of power is also bidirectional. When the demand for electric power is measured and accumulated over a period of time, the result is the sum of all work accomplished over that period. Electric meters at the utility entrance to buildings do exactly that. They total the amount of energy flow at the end of the month. This is a true measurement of electrical energy supplied by the utility company to the measured premises.

The motors that move elevators are power-converter devices. Electric power goes in (volts X amps or watts) and gets converted to mechanical power (torque X rpm or horsepower). Motors and generators are constructed alike and operate in much the same way. All electric motors can act as electric generators. Each time the shaft of a motor is mechanically forced to turn faster than the electric power source, it causes mechanical power (torque X speed of the turning shaft) to be converted to electric power (volts X amps). Therefore, power can flow in either direction through an electric motor. This is true of DC motors, with or without brushes; asynchronous AC induction motors; and permanent-magnet (PM) synchronous motors. This principle allows energy temporarily stored in the mass of a moving elevator to be recovered.

Adjustable speed drives (ASDs) are a form of electrical power converters typically used to convert the fixed voltage electricity of utility-line mains to adjustable voltage that controls the speed of elevator motors. ASDs are often thought of as being only AC drives and motors, but the speed of DC motors can be easily adjusted by voltage control and have been doing so to operate elevators for many years. Ward-Leonard-style motor-generator (MG) sets are a form of DC drive, as are silicon-controlled rectifier (SCR)-DC adjustable speed controls. In either case, adjusting the voltage (and frequency of an AC drive) is the primary mechanism by which to control how much power flows to or from the motor.

When the power converter provides voltage in excess of the counter voltage (counterelectromotive force [CEMF] generated internally by the rpm of the motor), electrical power flows into the motor to create the accelerating or lifting torque on the shaft and elevator sheave. When the power converter output voltage is less than motor CEMF, the motor acts as a generator to transform mechanical power (torque X speed) into electricity that flows backward into the power converter. The design and type of electrical power converter used to adjust motor speed affect what happens to regenerated energy provided by the lift motor.

**DC Elevator Motors with Ward-Leonard (MG Set) controls**

The Ward-Leonard MG set is an AC induction motor connected to utility lines that turns the shaft of a DC generator at a relatively constant speed. The DC elevator motor is connected to the output of the generator. Adjusting the field strength of the generator directly varies the output voltage applied to the DC elevator motor. The value of generator voltage in relation to elevator motor CEMF determines the direction and magnitude of actual power flow. When the elevator motor is providing braking force on the load, power flow is from motor to generator. The generator then acts like a motor and attempts to speed up the shaft connected to the AC induction motor. As the induction motor is pushed slightly faster than the utility frequency and voltage allow, it essentially becomes an induction generator, creating and pushing AC power back into the utility lines. Equipment efficiencies come into play, but the fact that an MG set regenerates is often overlooked. Even though the AC motor on the MG set draws a significant amount of current at a low power factor when idle, the utility-line current is always free of harmonics.

**DC Elevator Motors with SCR-DC Drive Controls**

An SCR-DC drive converts utility AC voltage to a variable DC voltage by a selective rectification process known as phase control. The SCR devices act like switches to connect specific portions of the AC utility voltage sine waves to the DC motor. Adjustment of the phase timing of each SCR switch in relation to the instantaneous AC voltage varies the average DC voltage applied to the motor. A dual SCR bridge circuit allows motor current to flow in either direction to and from utility lines. Adjusting the average DC output voltage of the power converter in relation to motor CEMF controls the direction and magnitude of power. The SCR power conversion process is particularly efficient when motoring or regenerating. However, the variable-voltage phase control mechanism does create significant current harmonics on utility lines in either operating mode with a widely varying power factor.

**AC Elevator Motors with Inverters**

Speed and torque of an AC motor, be it synchronous or asynchronous, is controlled by an electronic power inverter adjusting the frequency and voltage applied to motor terminals. There are several types of inverters, and all use rapidly controlled electronic switch pulsing (pulse-width modulation) to convert constant voltage from a temporary DC voltage source, or bus, to three-phase, variable-voltage AC at an adjustable frequency. Although various technical schemes are used for precise control, motoring occurs when the voltage and frequency applied to the AC motor is greater than the CEMF generated inside the motor in proportion to rotating speed. Power flows from the DC source, through the inverter and motor to the mechanical load. When the applied voltage and frequency are less than the generated CEMF, the motor will act like a generator. Mechanical power pushing on the shaft is converted to electrical AC power by the motor, and the inverter directs that power back into the DC bus.

**Non-Regenerative Inverters**

Many inverters for AC motor control have a one-way power rectifier on the front end to convert AC voltage from utility lines to DC voltage that is temporarily stored on an internal capacitor filtered power bus. This is the ideal low-cost way to provide DC voltage for operating an inverter controlling an AC motor. However, the rectifier can pass power in only one direction. Whenever elevator operation is such that the motor and inverter are regenerating power to control the speed of a gravity-fed overhauling load (empty car up or full car down) or simply extracting out kinetic energy to slow down the moving mass, energy will be pumped into the DC bus, resulting in an increase of voltage on DC bus storage capacitors.

The conventional way to resolve excessive voltage buildup is to add a circuit that temporarily turns on a switch to dump excess energy into a bank of resistors. Resistive braking is one way to handle energy returned from the elevator equipment, but it represents pure losses to the measured electrical consumption. There are other losses related to efficiency of the elevator equipment system, but 25-40% of the total elevator energy consumption is typically lost in the resistor bank. Heat released by the resistors must be removed from the control room. One must pay an additional amount for any power used to operate ventilating fans or air-conditioning units that may be required to remove heat away from the resistor bank.

**Regenerative Add-on Modules**

A power-regeneration module can be added to most conventional motor-control inverters to regulate power flow from a DC source back into utility power lines. Operation is similar to a second inverter operating in synchronization with the power-line frequency. When elevator motor and inverter action pumps power back into the DC bus, causing the voltage to rise higher than the utility line peaks (empty car up or full car down as explained above), the regeneration module pushes excess power back into utility lines. This action keeps the rise in DC bus voltage under control such that the DC braking resistor is not used. The energy that would have been wasted as heat in a braking resistor is returned to the utility distribution system. This makes a significant difference in overall energy consumption, particularly with a low-friction PM gearless elevator system.

**Where Does Regenerated Energy Go?**

Electric power distribution within a building facility often takes one of the forms illustrated in Figures 1 or 2. A single-use building, such as a corporate office or hotel, may have a single utility meter located where the utility power enters the facility. Mixed-use commercial buildings have a combination of common-use electrical equipment for hall lighting; heating, ventilation and air-conditioning (HVAC); and elevators, as well as individual metering for multiple tenants, such as restaurants, business offices or apartment dwellings. The utility distribution voltage step-down transformer may be outside in a neighborhood utility vault or on a local utility pole for smaller buildings. Large buildings often have a substation step-down transformer built into the basement or other convenient location. In either case, there is a metered power

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distribution center (breaker panel) where multiple wiring feeders spread out to other areas within the building. Elevators usually have their own power riser dedicated to that service, but elevator feeders are almost never separately metered.

Even though the combined horsepower rating of all the elevators may be large, elevator operation is sporadic, and the actual electrical load is relatively small compared to the sum of continuous loads of other feeder branches attached to the same distribution panel. The total of all power drawn by electrical loads in the building is measured by the utility meter, and the rate that the utility meter spins depends on night or day occupancy conditions, outside temperature, other machinery use and whether or not the elevator lift is in operation. Note that when the elevator equipment regenerates, power can flow directly back to the distribution panel and out to some other equipment already in use within the building without passing through the utility meter.

During the few seconds in which elevator regeneration occurs, the meter doesn't need to run backward; it simply slows down while the energy recovered from the elevator momentarily helps to power a different elevator, operate lights in the hallway or run the HVAC fans. There are no other noticeable effects, such as voltage surges or distortion, which can cause lights to blink or other electronic equipment disruption. Some of the energy that was once metered and used to start the elevator moving or lift the load is recovered and used again to perform a different task within the building. A smart building owner will notice that using the same energy twice results in reduced utility costs.

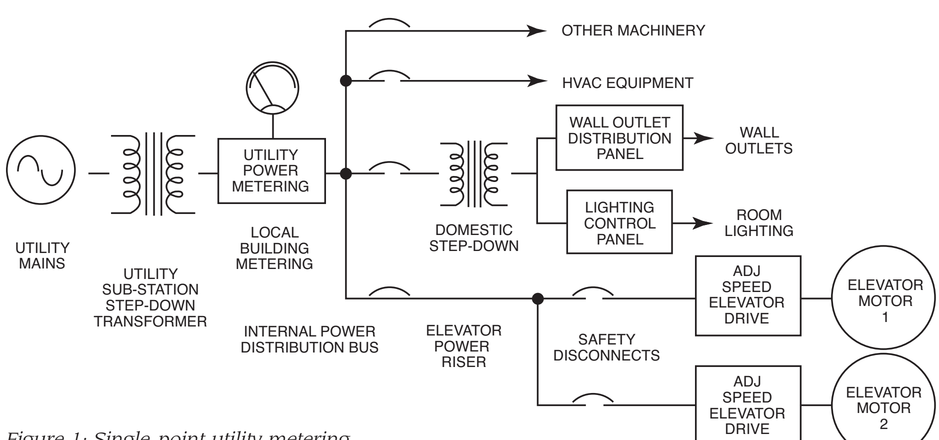


*Figure 1: Single-point utility metering*

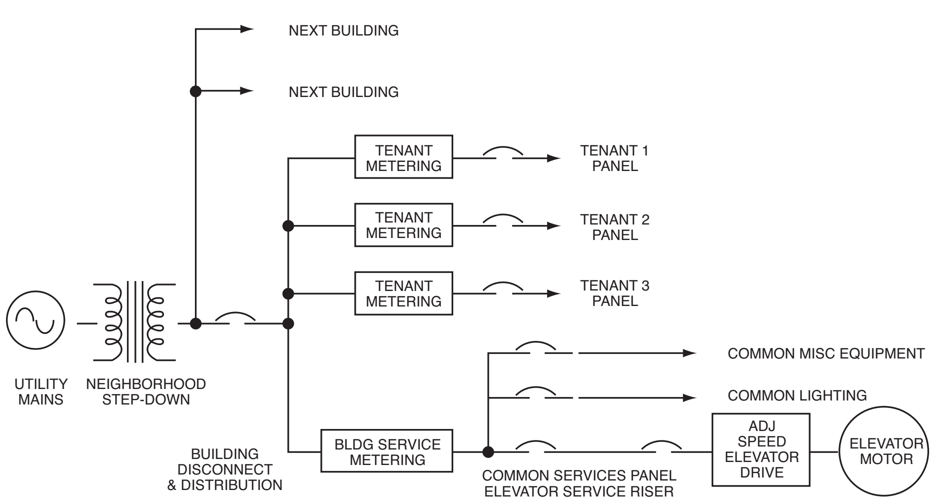


*Figure 2: Multiple-tenant building with individual metering*

Be aware that the nameplate rating on an elevator motor (in volts, amps, horsepower or kilowatts) is based on the power it takes to raise the maximum rated payload of the elevator at rated speed. However, the elevator is not always loaded to rated capacity, and it only operates for short periods of time. Also, efficiency losses dictate that the total of regenerated power will always be less than that required for full-load-up service, and it can regenerate power less than half of the operating time. The end result is that only a small portion of the full load electrical rating of the elevator is regenerated during a typical day, and it is an even smaller portion of the total energy consumption of the entire building.

***Regeneration Versus Cogeneration***

Although it may sound the same, there is a significant difference between a regenerating elevator system and cogeneration. A cogeneration (wind turbine, fuel cell, photovoltaic or waste gas recovery generator) system is intended to operate at near capacity almost continuously. The goal of cogeneration is to supply a major portion of the energy required for the local premises or even sell electricity to the utility company for distribution to other paying customers. Power regenerated by elevator equipment is sporadic and relatively small. It is intended to save energy by recycling it to be consumed by other loads within the building. Using reclaimed energy for a useful purpose rather than wasting it as heat is an effective form of overall energy conservation.

When an elevator drive regenerates, the recovered power actually flows backward into the utility system. In most cases, local electrical loads will absorb the energy before it reaches the kilowatt-hour meter. If local loads are not large enough to absorb all the regenerated power, it will still flow backward into the utility system.

However, many utility meters are ratcheted so that they will not run backward, but power will still pass through them toward the distribution grid. Energy will be conserved, but the building owner will not necessarily receive the full monetary benefit.

In the event that emergency power generators are used to operate elevators when utility power is not available, energy-absorbing loads must also be attached to the same generator. An emergency-power consumption analysis should be performed in order to determine the minimum size of generator to be used for this purpose. Very often, lighting and HVAC loads powered by the same generator will absorb all regenerated energy from elevators. However, operating only a single elevator from an equally sized emergency power generator will not work, due to the sporadic nature of elevator operation and the inability of the generator to absorb any significant amount of regenerated energy.

One can reduce the magnitude of regenerated energy by reducing elevator speed during emergency power situations. The maximum amount of regenerated power and energy will be reduced in direct proportion to any reduction in operating speed. The internal losses in most elevator systems will allow operation up to 10-15% of rated speed without regenerating any significant power back into utility or generator supply lines.

In the case of elevator drives with an add-on regeneration unit, it may be possible to use control logic to disable regeneration and engage conventional dissipative resistor braking under emergency power conditions. It is more difficult (and costly) to provide for backup dissipative braking on elevator drives designed to automatically regenerate while controlling utility-line harmonics and power factor. Most elevator equipment furnished today is not designed to have its regeneration feature turned on and off.

Other safety concerns related to regenerating elevator drives are unfounded. Motor control drives, those with and without regeneration ability, are designed with features that sense the condition of utility power. This is a design necessity in order to be a reliable product in the elevator industry. If utility power is weak or fails unexpectedly while the drive is in operation, it must sense the poor power condition and shut down in a controlled manner in order to survive. If utility power is interrupted while an elevator is in flight, the drive will quickly sense that condition and shut down. According to elevator safety code rules, interlocked control circuits will also engage the mechanical brake to bring the elevator to a safe stop when the drive ceases to operate. Elevator code also requires overspeed protection in the form of a governor with an electrical switch that opens control circuits that turn motor controls off and engage the mechanical brake. On high-speed lifts, there may be an additional motor dynamic braking circuit to further assist in the braking effort. The combination of these features means that an elevator will be quickly and safely brought to a halt, even if it happens to be regenerating at the time of power disconnection.

The faulty-power-sensing mechanism of regenerative drives mentioned above will cause the drive to shut down within fractions of a second in the event of a utility power disconnection. Energy of the moving elevator will be transferred to the mechanical braking system as the elevator is brought to a halt. It will not continue to be injected into the utility line.

Regeneration occurs naturally in thousands of buildings all over the world, as long as the utility system remains healthy and strong. The massive capacity of the utility grid allows the momentary energy required to operate an elevator to flow in either direction and be relatively unnoticed in large buildings. True regeneration captures a large portion of the mechanical energy operating elevators and puts it back into the electrical system, where it can be reused by another elevator or to power other electrical loads. Capturing the regenerative energy can help to conserve and minimize energy use, which will certainly help save money and conserve energy supplies.

**Donald Vollrath** is a principal engineer of the Elevator Drives division of Magnetek, Inc., headquartered in Menomonee Falls, Wisconsin. He has more than 40 years of experience developing AC and DC motor drives and controls for industrial applications. During the past 20-plus years, Vollrath's work has shifted almost exclusively toward designing and perfecting the application of several generations of general-purpose and custom motor control equipment for elevators. He holds a BS in Electrical Engineering from the University of Illinois.

**Learning-Reinforcement Questions**

Use the learning-reinforcement questions below to study for the Continuing Education Assessment Exam available online at www.elevatorbooks.com or on page 127 of this issue.

- Why are elevators counterweighted?
- What is the difference between power and energy?
- Which three main factors determine how much power is required to operate an elevator?
- What is meant by bidirectional power or energy flow?
- How does weight of the elevator equipment figure into the energy requirement?
- What controls the flow of power through an elevator motor?
- What provides the energy to lower an elevator load?
- Which type of motor controls can and cannot regenerate?
- Where does the energy go if the drive cannot regenerate?
- How does regeneration actually save on the utility bill?
- What happens to the energy if there is a utility power failure?

## ELEVATOR WORLD Continuing Education Assessment Examination Questions

**Instructions:**

- Read the article **"Regenerative Elevator Drives: What, How and Why"** (page 95) and study the learning-reinforcement questions.
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1. What does the utility meter measure?
   a. Peak kilowatt demand.
   b. Average kilowatt-hour demand.
   c. Kilowatt-hour consumption.
   d. Kilovolt-ampere consumption.

2. What most affects the peak power demand of an elevator?
   a. Whether the drive can regenerate.
   b. Operating speed X capacity.
   c. Acceleration rate X equipment mass.
   d. The type of elevator drive.

3. What most affects the overall energy consumption of an elevator?
   a. Operating speed X capacity.
   b. Acceleration rate X equipment mass.
   c. The type of motor.
   d. Whether the drive can regenerate.

4. How do electric motors regenerate?
   a. The motor runs faster.
   b. The motor acts like a generator.
   c. They have PMs.
   d. Regeneration has nothing to do with the motor.

5. Which drives can regenerate?
   a. MG sets.
   b. AC inverters with diode rectifiers.
   c. SCR-DC drives.
   d. Both a and c.

6. If an elevator drive can regenerate, where does the energy go?
   a. It heats up braking resistors.
   b. It temporarily powers other loads within the building.
   c. It heats up the motor.
   d. It gets stored in the adjustable-speed motor drive.

7. What happens if there is a utility power failure while an elevator drive is regenerating?
   a. The drive will blow up.
   b. The elevator uses the brake to stop.
   c. People in the neighborhood may get electrocuted.
   d. The elevator overspeeds.

8. If an elevator drive is not designed to regenerate, where does the energy go?
   a. It is wasted as heat into the brake.
   b. It is wasted as heat into the motor.
   c. It is wasted as heat into a resistor bank.
   d. It is wasted as heat into the drive.

9. Does regeneration disturb other utility customers?
   a. No, voltage distortion that other customers see will be no different than with a non-regenerative motor drive.
   b. Yes, they must be disconnected.
   c. Yes, they will be disturbed by current harmonics.
   d. Yes, regeneration causes the line voltage to sag and surge.

10. To be compatible with a regenerative elevator drive, an emergency power generator needs to:
    a. Be equal in kW size with the elevator motor.
    b. Be greater than two times the kW size of the elevator motor.
    c. Have other loads attached to absorb all regenerated power.
    d. Have switchable loads to accept regenerated power.

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