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Why PWM-DC?

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The Short Answer

When limited to the context of passenger or freight elevators, a short answer to the primary question comes from understanding how motor controls (or 'drives') work and their requirements for successful operation of an elevator. In part, some of the answers are circumstantial. Other influences come from practical issues of cost, an increasing awareness of energy conservation as well as being environment friendly or "green". This leads to the following conclusions.

1. There is a large installed base of gearless DC elevator machines in mid-rise and high-rise buildings being operated with outdated m-g sets or aged SCR controls.

2. Retrofit (pulling out the old and replacing with new) of an existing elevator machine still in good working order is unnecessary and can be very expensive.

3. In mid-rise and high-rise buildings an equivalent gearless AC motor and drive equipment are expensive or may not even exist at the necessary elevator power level. (Capacity X Speed)

4. Large elevator drives need to regenerate during operation in order to conserve energy and keep operating costs to a minimum. (Up to 40% energy savings)

5. Electric utility usage needs to improve by using equipment with a high power factor.

6. Electric utility usage needs to improve by using equipment that has low harmonic current content.

High power low rpm gearless DC elevator machines are large and very special. In many cases today there is no equivalent AC motor powered machine. Even at the power levels where an AC machine does exist, removing a perfectly good DC machine makes little sense, as doing so might be prohibitively expensive.

SCR-DC drives, which inherently do regenerate, are capable of operating the largest of elevator motors. Unfortunately, they have undesirable drawbacks of widely variable power factor and high utility line harmonics.

Harmonics can be cleaned up by the addition of an electronic filter, but the variable power factor cannot. AC drives, on the other hand, have similar harmonics, but the perceived power factor is more acceptable. However, low cost AC drives by themselves cannot regenerate. Equipment can be added to allow it to do so, but that practically doubles the cost and size.

In order to achieve regeneration, low harmonics and high power factor, one needs to consider using two higher frequency PWM (Pulse Width Modulation) concatenated back-to-back controllers. The first is to interface with the utility line, regulating harmonics and power factor, and the second regulates motor operation. The PWM-to-PWM dual converter/inverter does just that. A PWM inverter can also be made to modulate power to a DC motor.

This is exactly what the Magnetek Quattro PWM-DC power converter does. The PWM converter, meeting EN12015 standards and recommended guidelines of IEEE-519, controls utility side harmonics and power factor right at the product terminals.

Output power to a DC motor is also controlled with PWM. However, the designed power level of Quattro drive equipment is intended for use in the 35 hp and larger category (500Vdc, >50Adc). The product is packaged as a complete integrated (non-separable) unit for a total solution in minimum space.

PWM-DC is not for every application. It may make more economic sense with a geared elevator machine, to replace the DC motors with an AC motor and drive simply because the motor is operated at a much higher rpm, similar to lower cost industrial-type motors. Geared applications also tend to result in lower power consumption where the need for improving harmonics, power factor and energy savings may not be that important.

A Brief Evolution of Elevator Drives

Electric motor controls for elevators many years ago were very crude. Starting, stopping and being able to get payload to the next landing were about the only constraints. Technical changes along the way have made significant improvements toward reliability of operation as well as the safety and comfort of passengers. Motor controls have transformed from jerky across-the-line starting to 2- or 3-speed step starters to variable speed drives.

One of the most useful and popular variable speed drive types is a DC lift motor powered and controlled by a variable speed Ward-Leonard motor-generator set. At first, these also had only a few pre-set speeds selected by relays and resistors. Later control improvements included infinitely variable generator field controls, achieving greater smoothness of the passenger ride and accuracy of arriving at the landing.

In the 30-40 year building boom after World War II, many thousands of elevators, large and small, were installed using DC motors and m-g set controls. However, in the 1980's the rotating electromechanical machines started to lose favor. Elevator modernization projects were performed using Silicon Controlled Rectifier (SCR) controls because the m-g sets were often noisy, required frequent service and were not nearly as efficient as the solid state SCR control replacements. SCR drives are all electronic and much more efficient than the m-g set…and could control the same DC motor that was already installed in the building which was still in good working condition.

Meanwhile, many smaller elevators were being installed with lower cost AC induction motors and retrofitted with SCR-based variable voltage starters replacing older multi-step starters.

In the late 1980's and throughout the 1990's variable voltage – variable frequency (VVVF) AC motor drives (inverters) were developed and installed on many of the small and not-so-small AC motor driven elevator systems. These VVVF and improved "Vector Controlled" drives also provided smooth performance and high power conversion efficiency making them attractive alternatives to DC motors and SCR drives, particularly at the 5-30 horsepower level.

Today, the increasing cost of electric power, the taxing of existing electrical distribution systems and interference between different types of electronic and electrical equipment has caused users and governing bodies to become aware of some of the drawbacks of SCR and low cost VVVF inverter controls.

Wasting energy is … wasteful and costly. Causing electrical interference with other equipment is also costly in the end. This has led us to the next level of energy conservation and being "green".

The Need for Regeneration

If SCR-DC and VVVF-AC electronic motor controls are so much more efficient, why is there waste? As the elevator industry has matured, a certain amount of design uniformity has taken place.

The passenger 'cab' is a metal reinforced structure supported or hung by steel cable 'ropes' and counterbalanced with a heavy weight. The counter-weight allows a smaller motor to overcome the effects of gravity while moving the car and passenger payload up and down. The ideal fixed counterweight is equal to the mass of the entire cab, plus about 45% of the rated payload (passenger weight) capacity. This yields a good compromise in the balance with gravity to minimize the motor lifting torque required for statistically typical loads. However, the cab, counterweight and all support ropes must also be in motion in order to move the passengers riding inside.

What happens is the effective total mass of those moving mechanical components is roughly 4 to 5 times the rated payload capacity of the elevator. The significance of all this is every time the elevator is moved, energy must be added to all the moving mass, not just the passengers, to make it accelerate. Moreover, like an automobile, when the elevator needs to decelerate to a stop, all that energy of motion must be removed. In addition, whatever gets hauled up comes down at a later time, so whatever potential energy is added to the mass to raise it against gravity will eventually need to be removed when it is lowered.

Energy can be removed by using a simple mechanical brake, which ends up wasting it in the form of heat. But if one can reclaim this energy and somehow return it back to the utility power distribution system as the elevator cycles hour by hour, day after day, the net effect would be to reduce the total amount of energy consumed… and measured for billing purposes by the utility company. This can represent significant energy savings to the building operator. The process of reclaiming otherwise wasted energy is known as regeneration. All electric motors can regenerate but not all drive types. In particular, AC motor inverters typically used in most low cost VVVF, vector control and PM (Permanent Magnet) motor drives cannot regenerate because they contain a one-way rectifier to draw power from utility lines. The motors and inverters can extract power from the mechanical equipment, but it is simply wasted (dissipated) by heating up a Braking Resistor.

The importance of regeneration depends on the overall power needs of the elevator and how often it is used. Many small elevators in 2 to 4 landing buildings travel slowly and are seldom used when compared to those in a busy hospital or high-rise office building. Low equipment cost is the main concern of building owners with low-power, low-usage elevators. Energy consumption is not a significant issue. However, the quantity of energy necessary to accelerate elevator equipment is proportional to the total mass multiplied by the square of the final operating speed. Taller buildings tend to have faster elevators and more need for people to use them. The elevators in taller buildings have a larger capacity (meaning more overall mass) and are used more frequently.

Furthermore, they have been designed using low-friction gearless machines to minimize wear and tear. Low-friction motion equates to fewer mechanical losses, leaving more energy of motion potentially available to be reclaimed. Consequently, most elevators using gearless machines, and particularly those designed for speeds greater than 2.5 m/sec (500 ft/min), will benefit greatly if the motor control equipment is regenerative.

The old-fashioned m-g set can regenerate, but not with high overall efficiency. An SCR-DC drive as well as some AC motor drives (used with an additional regenerative power package) can regenerate power efficiently. Typical elevators driven by modern solid state drives with regeneration can cut utility power consumption by 25-35% when compared to a similar non-regenerative drive type.

Power Line Pollution: Harmonics and Power Factor

Power line harmonics and power factor have recently become important issues. The power utility company, IEEE-519 guidelines and European EN12015 normative specifications are concerned about excessive amounts of current harmonics and poor power factor. These directly affect the size of necessary substation transformers and feeders. IEEE-519 guidelines also recommend specific limits of current and voltage distortion to minimize electrical noise interference of equipment at the point of common connection (PCC).

An analysis of typical building installations shows that most elevator equipment rooms are supplied by separate electrical feeder wiring directly from the main source of power to the building. Those feeders also suffer from the effects of additional harmonics caused by conventional SCR-DC or Rectifier/Inverter-AC drives. These can cause unwanted wire and circuit breaker heating, and, in some cases, acoustical noise.

Current harmonics are created by rectifiers, both SCR and diode types, drawing power from utility lines in sub-cycle bursts rather than in continuous sinusoidal fashion. Any current that is not sinusoidal contains harmonics, typically 20-25% for SCR drives and 45-75% for rectifier/diode front-end type inverters. Most 'Regen' module products added onto AC inverter drives making them regenerative also create harmonics. Reducing harmonics in the elevator equipment room with these types of motor controls requires specially designed reactors and trap filters. The irony of the relatively inefficient motor-generator set is that the induction motor turning the generator actually causes no power line harmonics.

Rectifier-fed inverter drives are often thought of as having unity power factor. This is only partially true in that current flows from each utility line only when the sinusoidal voltage on that phase is near the peak value. However, the real mathematical definition of power factor is pf = real power/apparent power, or Watts/VA, where the volt-ampere value must include the effects of all harmonics as well. Therefore, although the 'displacement' power factor may be near unity, the presence of 25% harmonic current can reduce the actual power factor down to 0.8 or worse.

Rectifier fed inverter drives do draw the utility line current in proportion to the instantaneous watts, or horsepower, being delivered to the load. At near zero speed practically no power (torque x speed) is being drawn. This tends to soften utility current demand transitions as motor torque and speed varies relatively slowly over an elevator lift cycle.

SCR-DC drives operate in a different manner in that utility line current is directly proportional to DC motor torque required at any speed, including when starting and stopping. Consequently, measured power factor of an SCR-DC drive during an elevator cycle varies widely from near zero to perhaps only 70-80% at top speed. This is simply an artifact of how phase controlled SCR drives work and cannot be fixed with any type of simple or expensive filtering.

However, there is a way to get regeneration, low harmonic utility line current and have true unity power factor. The method is to use an electronic inverter to regulate and control current on the utility side to always be sinusoidal (free of harmonics) and in phase with the utility line voltage (unity power factor). This application function is known as an active rectifier, or 'converter.' Power can be made to flow equally well in either direction to a DC bus or to the utility line (motoring or regenerating). A second inverter is then used to control power flow from the DC bus to an AC or DC motor in order to vary torque and speed as required to control the elevator.

Typically, IGBTs (Insulated Gate Bi-polar Transistors) are operated in a Pulse Width Modulation (PWM) scheme to control flow of power in a converter, in a manner similar to inverter control of an AC motor. However, simply connecting two complete inverters together to form a converter-inverter is somewhat wasteful of available space. A more effective approach is to design the converter and inverter into one fully integrated assembly, eliminating wiring between sections and minimizing the need for individual control mechanisms and segregated cooling apparatus.

Why keep using the DC Motor?

A valid question to ponder at this point is, whether one should keep using the DC motor or replace it with an altogether modern AC, or AC/PM motor. The answer lies in the awareness of several practical issues.

Thousands of large buildings were originally built with gearless DC elevator machines in the 35 to over 200 hp range. In most cases, although they may be 30 to 40 years old, the machines themselves are still in good working condition yielding excellent ride quality. Because of their special high-torque low rpm characteristics, these gearless DC machines are quite large when compared to an industrial motor of equivalent horsepower. So large that, in many cases, the enclosing parts of the building may have been completed after the equipment was installed.

Subsequently, replacing the machine may incur significant costs. Furthermore, although AC machine capacity has grown in the last few years, an equivalent rated AC machine and the inverter to drive it may not yet exist at a reasonable price…especially if there is a high cost associated with removal and replacement of a perfectly good DC machine.

An efficiency comparison of the motors themselves is: ~89% for DC (including motor field excitation); 90-92% for elevator type PM (synchronous) AC; but only ~80% for low rpm induction (asynchronous) motors. This does not offer a great incentive to swap out a perfectly good DC machine.

The most common sense and economical approach seems to be to re-use an existing DC gearless machine if it is in good working order.

Drive Type Comparison

A synopsis of all of the above is that the ideal elevator drive at larger horsepower levels should have efficient power conversion, regeneration, low harmonic distortion and near unity power factor at the utility power lines.

Table 1 on the next page shows a comparison and data related to those characteristics plus several other factors to consider with common types of motor controls. The check marks indicate superior performance of a particular characteristic.

Table 1. Characteristic Features

Customer Desired Features	SCR-DC Motor Drive	Diode - PWM Inverter AC or DC Motor	PWM-to- PWM Convrtr - Invrtr AC or DC Motor
Smallest Volume	Unit is small but requires external transformer & ripple filter	✓	Compact when designed as an integrated unit
High Efficiency Power Conversion	98-99% but only ~90% with required xfmr and ripple filter	93 – 96%	92 – 95%
Regeneration	✓	No Requires 2nd Add-On Unit	✓
Low Utility Harmonics	Requires large trap filter	Requires large trap filter	✓ Less than 8%
Unity Power Factor	Not possible	0.80 – 0.93 typical	✓ 0.98 – 0.99
Flexible Output Voltage	Requires transformer	Must be less than input Vac	✓ May be above or below input Vac

Energy Savings

Estimating energy savings depends heavily on the equipment being compared, and the size and usage pattern of the elevator. The numbers listed below are for a 3.5 mps, 1,600 kg (700 fpm, 3,500 lb) car operated in a busy building. A typical motor for this application would be rated at ~38 kW.

m-g set powered:	104	kwh/day
SCR-DC w/ transformer & ripple filter:	77	kwh/day
Regenerative PWM-PWM-DC:	72	kwh/day
Regenerative Rect-PWM-AC:	64	kwh/day
Non-regenerative AC:	105	kwh/day

This calculated data shows that m-g set powered controls suffer from a combination of poor power conversion efficiency and the fact that the m-g set uses up electricity while spinning idle for at least part of a typical day. An SCR-DC drive operating that same motor would save ~26% in power consumption. The results with Quattro PWM-DC are slightly better, ~31% savings, with clean harmonics and unity power factor.

By contrast, the AC inverter with a Regen add-on package driving an AC motor seemingly saves another 11% over the Quattro-DC, but it still has harmonic currents. It is worthy to note the results of using a non-regenerative AC drive. Although the motor and inverter might be more efficient, dissipating possible reclaimable energy in a resistor bank causes that combination to actually use the same, or even more, energy than the original m-g set and DC motor.

Conclusion

The conclusion of the above discussion is that if the proposed hoist way already has a 35 hp or larger gearless DC machine in good working order, there is no economic incentive to convert to an AC motor solution. Several different types of motor controls are available to control either AC or DC machines. But, re-using the existing DC machine makes good sense.

However, improving the application to be environmentally friendly or “green” requires that the selected equipment should regenerate, be low in power line harmonics and have unity power factor. For that a PWM-to-PWM dual converter such as Quattro-DC is the most practical solution.