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**SUBJECT: Utility Power Factor of DC Elevator Drives**

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DC motor controls with SCR type power conversion have three unwanted characteristics that affect their acceptance of use by customers. The SCR power conversion process produces harmonic currents on the AC power line, SCR commutation produces line notch electrical noise which can get into the utility distribution system, and the power factor of demanded line current is somewhat proportional to motor CEMF/speed. Although these affects exist, they are not necessarily large enough to cause significant problems in buildings where SCR type DC drives are used to control passenger and freight elevators. But there have been many recent requests for providing additional information and or product changes or product enhancement devices (filters) to make elevator controls comply with IEEE Std 519. Most of the undo alarm is caused by misunderstanding of terms and misinterpretation of the industry ANSI-IEEE-519 practice guidelines. This application note addresses only the issue of utility power factor.

Power Factor is defined as the ratio of the total power input in watts to the total volt-ampere input required at the point of connection to the power supply system. This ratio takes into account all effects of harmonic components of current and voltage and the effect of phase displacement between current and voltage. Volt-amperes is the product of rms voltage and rms current. There are two predominant phenomena that contribute to lower the power factor of SCR DC drives - That of current distortion caused by rectification which raises the rms content of line current above that of an equivalent sine wave, and a phase displacement of current in relation to the voltage sine wave supplied by the utility.

$$PowerFactor = \frac{RealPower(Watts)}{ApparentPower(VA)}$$

where:

$$ApparentPower = V_{RMS} \times I_{RMS}$$

$$I_{RMS} = \sqrt{(I_{Fundamental})^2 + (I_{Harmonics})^2}$$

The current waveform and harmonics caused by 6 and 12 pulse rectifier (diode) and controlled rectifier (SCR) drives have been studied by many. It turns out that the utility line current supplied to a 3-phase 6-rectifier front end, in continuous conduction as used for an AC motor inverter, and that of the 6-SCR DC drive are identical (with similar utility line impedances). So at best, the harmonic content of current between these two motor drive types are the same. In a similar fashion a 12-pulse rectifier or SCR drive will also have the same power line harmonics. The books tell us that the sum of current harmonics of a 6-pulse rectifier will be about 33% of the fundamental current amplitude. The total rms current will then be the square root of the sum of the squares, or 1.053 times that of an equivalent sine wave. (See the equations above.) The maximum power factor for a 6-pulse rectifier or SCR power controller will therefore be 1/1.053 or 0.95. A 12-pulse rectifier or SCR control will have about 13.5% harmonic line currents, resulting in a maximum power factor of 0.988. In either case the power factor reduction caused by current harmonics of either a 6 or 12 pulse SCR motor drive is minimal and is certainly acceptable to most customers.

But an SCR drive power converter produces a DC voltage output from an AC utility voltage supply by selectively switching segments of the AC line to line input voltage sine waves and connecting them to the DC output terminals. The DC output voltage is adjusted by delaying SCR triggering to lag the

position of current flow from that which would be supplied from an equivalent all diode rectifier circuit (no SCRs). Current that flows to the load is controlled indirectly, following Ohm's Law. This current flows directly through load, the SCRs, and utility lines, and will lag the voltage sine wave in phase timing. This is what phase controlled power conversion is all about. The SCR delay in current causes what is referred to as a lagging displacement power factor. The net effect for an SCR controlled DC drive is that when the desired voltage output is high, the power factor can be as high as that identified above, but when the desired output voltage is low the current will lag behind the voltage and the power factor will also be low, near zero if the desired output voltage is close to zero. It is the displacement power factor that is of concern to DC drive customers. Note that this effect is caused only by the ratio of DC output voltage to AC input voltage. It is independent of the choice between 6-pulse or 12-pulse type drives.

Elevators must always be operated to start and stop at zero speed at a landing, where the DC lift motor will have zero CEMF. This means that an SCR drive will always start and stop at near zero power factor conditions on the AC line. As speed increases up to running speed, the CEMF, V<sub>dc</sub> motor voltage, and power factor will increase. But an elevator is a cyclic load with significant inertia. When it starts and stops, high DC armature and AC line currents are necessary for a few seconds to accelerate/ decelerate the inertia. This will begin and end at a very low power factor. When running at rated speed, for 1 to perhaps 20 seconds depending on travel distance, a significantly lower current is required, but it will be at a much higher power factor. While waiting at a landing, no current is required (except for auxiliary equipment). Just obtaining a meaningful measurement of the power factor is problematic.

IEEE-519 guidelines give few clues on how to characterize cyclic utility loading as is caused by an elevator. However, other consultation documents written as interpretive aids for IEEE-519 indicate that a proper industry practice for harmonic current measurements is to average harmonic current demand amperes over a 15 or 30 minute interval to determine meaningful numbers for Total Demand Distortion. This method is similar to that already in use by utility metering equipment to determine maximum KVA demand for utility customer billing. The 15 minute averaging method is meaningful to the utility because they are concerned about long term heating effects of transformers and distribution cable equipment. Occasional higher power demands lasting less than a minute are of little bother. Since power factor is an indicator of potential KVA heating, it should be appropriate to use a similar averaging technique to measure and determine a meaningful power factor of a motor control drive used for an elevator. It is important to understand that the recorded measurements must be in absolute numbers, rather than as a percentage of actual consumption. Time averaging of that data must consider the total power demand in order to determine an average power factor and the effects that it might cause on the utility system. The reason is simple...No one cares if the power factor is poor, when the ampere demand is small compared to the total capacity of the utility distribution system. [i.e. – The power factor of a 4 VA doorbell load is not important to a 20 ampere, 120 volt branch circuit.] A specific technique to avoid is to use a one-time measurement to capture worst case data of peak KVA or poorest power factor and then assume that these numbers are valid for all time. This would represent only a worst case scenario, but be relatively meaningless on an average basis.

### Power Factor Estimation

A passenger elevator in a high rise office building could have the following characteristics:

Full Load Amps = 122dc/100ac, Vdc = Vac = 400 (transformer secondary), Accel time = 2.5 seconds,  
 Average flight time = 15 seconds floor to floor, PF at Run velocity = 0.85,

At-floor idle time = 10 seconds, Average usage during 24 hrs = 50%.

The average load is 43% which happens to coincide with counterbalancing, so the average current required while Running at rated speed is small, say 0.2pu current. [This is why it is counterbalanced at 43% of payload capacity.] This will require Iaccel of about 2.2pu. For other conditions...

Empty car – Run amps = 0.6 pu, Iaccel = 2.0pu

Fully loaded car – Run amperes = 1.0 pu, Iaccel = 2.5pu.

AC line current and KW demand profiles are shown in the attached sketch for typical elevator runs. During deceleration, the unit regenerates about 90% of the kinetic energy of inertia back to the utility system. Using the assumptions above for a 15 minute period of continuous activity with full load going up and an empty car coming down, such as might occur during the early morning rush would produce the following averaged Per Unit data (18 complete up-down cycles in 15 minutes). Note that work is done lifting the payload (full up) and then lifting the counterweight (empty down).

Apparent Power Calculations:

KVA-Seconds for Accel & Decel =  $18 \times 2.5 \times 2.5 \times 4 = 450$  pu KVA-Sec

KVA-Seconds for Running time =  $18 \times 10 \times 1 \times 2 = 360$  pu KVA-Sec

Total pu KVA-Seconds for 15 minute period = 810

Real Power Calculations: Assume IR drop of 8% at rated current, 0.08pu

Motor losses during Accel-Decel  $18 \times 2.5^2 \times 0.08 \times 4 = 36$  pu Watt-Sec

Motor losses during running  $18 \times 10 \times 1 \times 2 \times 0.08 = 28.8$  pu Watt-Sec

Motor field consumption (5% of armature rating)  $18 \times 15 \times 2 \times 0.05 = 27$  pu Watt-Sec

Energy req'd to lift payload then counterweight  $18 \times 10 \times 1 \times 2 \times 0.85 = 306$  pu Watt-Sec

Accel/Decel energy not returned by regen  $18 \times 0.1 \times 2.5 \times 2.5 \times 2 = 22.5$  pu Watt-Sec

Total pu Watt-Seconds for 15 minute period = 420 pu Watt-Sec

$$\text{AveragePowerFactor} = \frac{\text{puWattSec}}{\text{puKVASec}} = \frac{420}{810} = 0.52$$

This is low. But is it really significant? The power isolation transformer (typical for DC elevator drives to better match motor Vdc) and the utility branch feeder for this elevator would be rated at  $100 \times 400 \times \sqrt{3} / 1000 = 70 \text{ KVA}$ . This is the KVA demand at rated elevator current. But 15 minutes at rated conditions represents  $15 \times 60 = 900 \text{ pu KVA-Sec}$ . So for the example 15 minute interval, the estimated average consumption was only  $810 / 900$ , or 90% of the 70 KVA rating. A building of the size to justify the example elevator will have other substantial electrical loads for lighting, HVAC, etc. It would not be unusual to have a 1,500 KVA capacity utility step down transformer to power building services, if not more than one. In most cases, the electrical feeders for elevator equipment will rise directly from the substation transformer without being tapped for other building loads. The secondary of this transformer then is the Point of Common Coupling (PCC) to other loads within the building. The average KVA load for the elevator during the example 15 minute interval is only  $70 \times 0.9 / 1,500 = 0.042 \text{ pu}$ , or less than 4.5% of the total transformer capacity. The importance of a 0.52 power factor on a 4.5% average load must be decided by the user.

### **Power Factor Correction**

IEEE Std 519-1992 describes various methods for system power factor measurement and correction analysis. It also warns about several pitfalls caused by placing power factor correction capacitors into a system with harmonic currents. If placed too close to a load that causes harmonic currents, high values of current will flow through the capacitors, causing potential damage. If correction capacitors are placed further away from the load, the system may resonate at one or more of the harmonic frequencies, again causing damage to capacitors and other connected equipment. See IEEE Std 519-1992, parts 5.2 – 5.4, and 6.5. These problems can be controlled by careful damping of the system. However, the random but yet cyclic nature of elevator operation poses the biggest obstacle for power factor correction. The KVA demand changes rapidly during the cycle, and the length of the run time is determined by the passengers. When the elevator is stopped at a floor, the KVA consumption drops to almost zero. Power factor correction capacitors left connected when not needed will continue to draw leading power factor current, and potentially cause voltage regulation problems. This makes it difficult if not impossible to determine an ideal value of fixed capacitive KVAR correction. Section 7.2 of IEEE Std 519 discusses several variable corrective schemes, either by switching capacitors in and out or with Static VAR compensators. But the automatic control equipment for these schemes will tend to work using time averaged measurements to prevent pulsing of the utility system. It is more likely to be out of step with actual second by second cyclic demands of an elevator, making the situation worse rather than better.

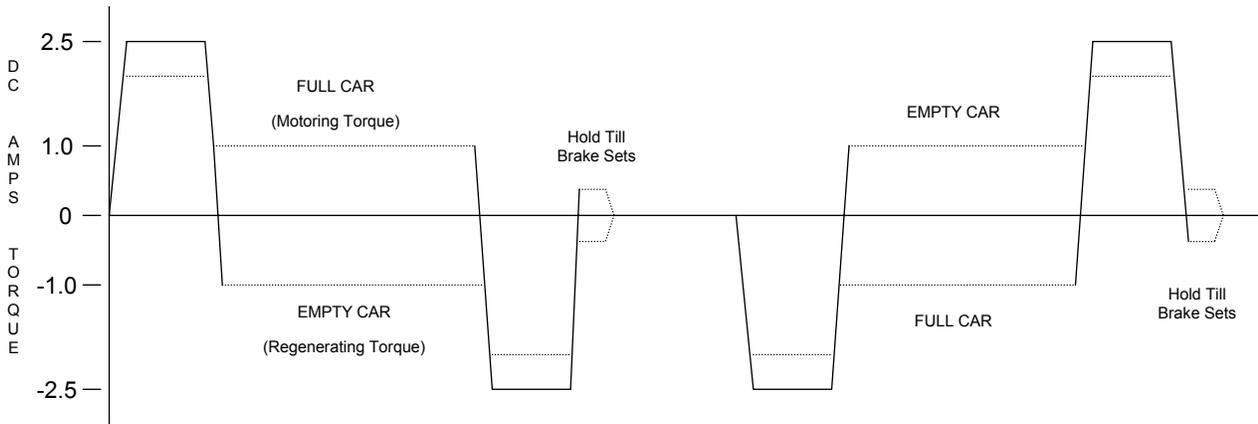
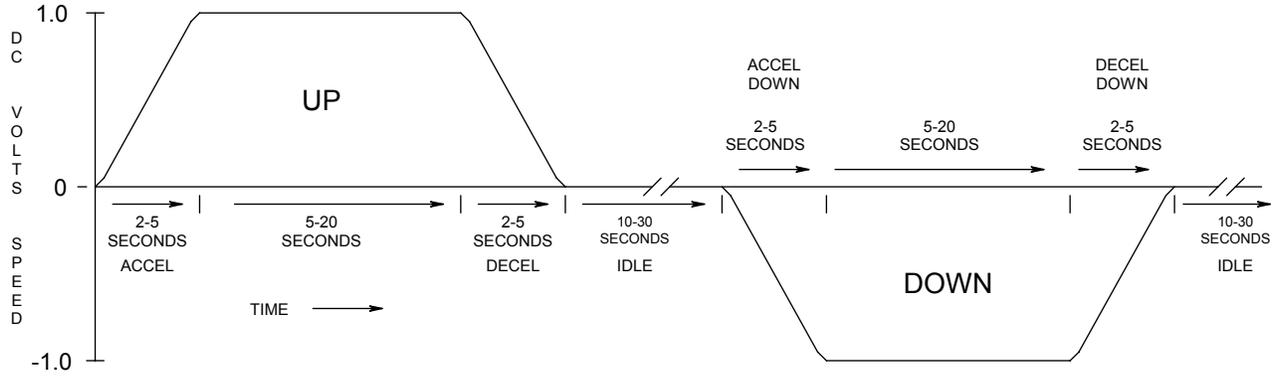
## **Magnetek Recommendations**

Utility companies are starting to put pressure on building management operators and consultants to reduce harmonic currents and improve power factor. The utility company is concerned only at the PCC with other utility users, i.e. – at the substation level. This is what IEEE Std 519 is all about. But building management consultants are attempting to meet this demand by requesting that all equipment connected within the building conform to the utility standard, so that the conglomerate summation will also conform. This is not a realistic nor inexpensive approach.

Magnetek recommends that elevator companies hire an outside power systems consultant to study and help obtain a plan for action. (It would not be unreasonable for several smaller companies to share the cost of consulting study.) The consultant company should...

1. Take actual use data on several typical buildings. Measure a single elevator and/or a whole multi-hoistway bank if possible.
  - a) Like the example above, record activity during active and inactive portions of the day.
  - b) Record KVA and Watt demand simultaneously Vs time during meaningful sample periods. A one time measurement is not valid data.
  - c) Find and record how the elevator equipment is being fed from the utility. How big is the main transformer? What size are the feeder risers? Where is the PCC for other building equipment?
  - d) Obtain electric utility use data for the study buildings. What is the monthly/daily power consumption? How does this compare with the utility equipment capacity? What is the average power factor? Estimate the portions contributed by elevators.
2. Discuss the harmonic current and power factor topics with the utility company(ies). Be sure to discuss the significance of...
  - a) The elevator KVA demand loading as a small portion of the total service size.
  - b) The cyclic nature of elevator demand loading.
  - c) The cyclic nature of harmonic currents drawn by elevator loads.
  - d) The cyclic nature of power factor drawn by elevator loads.
3. Inquire how the utility does or will measure and monitor user power factor for billing purposes.
4. Ask the utility for an opinion on...
  - a) The need for power factor correction of elevator cyclic loads
  - b) The need for harmonic current correction of elevator loads
  - c) Get a written opinion for both large (office) and small (apartment) building types.
5. Discuss these opinions with building consultants. Involve utility representatives to participate if possible so that a consensus understanding and agreement may be obtained.
6. If power factor correction equipment must be installed...
  - a) Consider first the placement of harmonic trap filters to elevator feeders to isolate harmonic currents from the power factor correction equipment. (Although it was demonstrated above that harmonics are not the big issue for overall power factor, adding a harmonic trap filter will help uncouple them from disturbing the power factor correction equipment.)
  - b) Be sure that the installing contractor for power factor correction equipment understands the cyclic operation of the elevator.
  - c) Do not place 'simple' power factor capacitors directly into the elevator drive equipment, nor onto the primary side feeders without a means to protect them from harmonic currents drawn by elevator equipment!

**ELEVATOR DUTY CYCLE**  
DC SCR DRIVE



NOTE - MAGNITUDE OF AC LINE AMPS ARE ALWAYS PROPORTIONAL TO DC AMPS  
PER UNIT KVA = PER UNIT AMPS = PER UNIT TORQUE

