Mechatronics for elevator installers and drive technicians!

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1 Introduction

The subject of emergency rescue for passengers trapped between floors in an elevator subsequent to a power failure is one, which deserves particular attention. Sooner or later the confined space in the car will induce stress levels, which must not be underestimated. Thus the ideal situation is that the elevator system - if possible without any kind of manual intervention- automatically move to a suitable landing after a power failure so the passengers can exit the lift. We have already touched upon the topic of emergency rescue in previous reports. At this point we would like to address some important details.

A certain minimum amount of electrical energy is required to carry out the rescue effort; power must be available for:

- Emergency illumination in the car
- Elevator controls
- Releasing and engaging the brakes
- Opening the doors
- Driving the car
- Further systems (Emergency intercom)

In the course of this discussion we will to observe primarily the energy required by the driving unit. The other using units will, of course, have to be taken into account in calculating overall energy needs during emergency evacuation.
There are several options available to supply power for rescue purposes during a period in which the normal electrical supply is down:

1. Muscle power - releasing the brakes and opening the doors manually, activating the hand wheel
2. Emergency power supply to the system by way of a generator delivering 1/3 phase AC power
3. Battery cabinet with rechargeable batteries U_{typ} 240V DC
4. UPS system using rechargeable batteries for energy storage, with a down line step-up converter delivering, for example, U_{ac}=230V 50Hz 1AC

Due to cost considerations the emergency power devices mentioned above are not normally engineered to cover the full rated power requirements for the system as a whole. (One exception might be the emergency generator using an internal combustion engine, with which normal elevator operations can be maintained for a short period of time.) These devices are, as a rule, designed for reduced- consumption elevator operation for a limited period of time. The specifications - e.g. full rated car speed - need not be complied with during emergency rescue operations. Using a lower travel speed during emergency operations in particular makes it possible to reduce appreciably the installed power output when employing a UPS (uninterruptible power supply) or battery cabinet.

2 Specifications

For the sample calculation we want to use as our basis the technical data which was already outlined in an earlier article (Engineering/Planning Elevator Systems, see Figure 8 there). As a reminder, we review the lift data utilized there:

Elevator

Payload m_n:	1000 kg	Velocity v:	1,6 m/s
Car weight m_{kab}:	500 kg	Gear ratio i:	57:2
Counterweight m_g:	1000 kg	Drive sheave diameter D:	0,6 m
Suspension:	1:1	Inertia J_g: (referenced to motor shaft)	0,3 kg*m^2
Max. acceleration a:	1,4 m/s^2		

Motor

Rated Power	P_n:	15 kW	Rated speed:	n_n:	1450/min
Rated Torque	M_n:	98 Nm	Rated current:	I_n	33 A
cosφ		0,83	Efficiency:	η_{mot}:	0,9
Nom. Frequency	f_n:	50 Hz	Nom. voltage	U_n:	360 V
Inertia	J_{mot}:	0,1 kg*m^2	Stator resistance	R_a:	0,22 Ω at 100°C

The following calculation is carried out on the basis of the data above and a typical UPS (uninterruptible power supply) or battery with the following specifications:

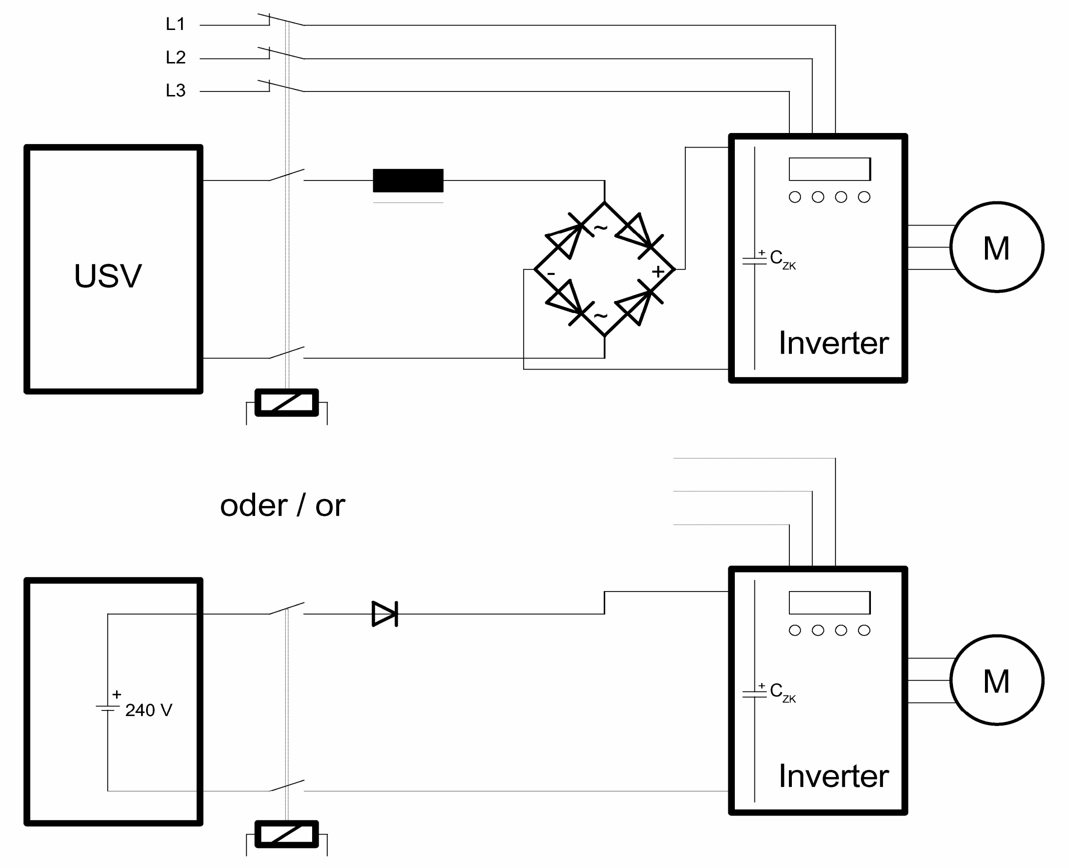
USV

Rated voltage:	$U_{e:}$	230 V 50/60 Hz
Rated power:	P:	3000 VA
Rated effective power:	P_{wmax}:	2250 W
Battery capacity:	BC:	4 * 12 V á 17 Ah

Battery

Rated voltage:	U_b:	240 V DC (20*12V in series)
Battery capacity:	BC:	typ. min. 3Ah

Wiring diagram (see also Figure 24 in the chapter on Safety/Commissioning):



3. Description of the circuitry shown above

A suitable interlock- using relays, for example - prevents normal operating voltage and the emergency rescue source being connected to the inverter in the same time. This is also ensured by the rectifier (at the UPS) or the isolating diode (at the battery) at the inverter's intermediate circuit. During line operation the nominal voltage in this intermediate circuit is many times higher than the voltage at the UPS or the battery. Thus, if there were direct connection, there would be a hazard of damage and under certain circumstances even explosion. The rectifier or diode must be designed to handle 3-phase line voltage at 400 to 500 V AC; this means that the blocking voltage will typically be between 1400 and 1600 V.
A part of the alternating current generated by the UPS is rectified for the inverter and fed to its intermediate circuit. Here a choke (or alternately a resistor which is jumped periodically by way of an auxiliary relay) damps the charging current to match intermediate circuit capacitance. By contrast, the DC voltage delivered by a battery cabinet can be fed directly, via the isolating diode, into the intermediate circuit (the rechargeable batteries used here can easily handle the brief charging current peak).

4. Functions required at the inverter and the emergency power supply

- It must be possible to operate the frequency inverter at low voltage!
- When the emergency power supply is switched through to the intermediate circuit while the latter is carrying no charge, it will have to tolerate a high charge peak. This peak must not cause the emergency power supply to shut down; any fuses or circuit breakers which may be incorporated will have to be engineered to handle this switch-on peak.

- The voltage at the UPS drops sharply during the switch-on phase. Its control circuit and all other system components to which emergency power is supplied must be sure to tolerate this drop and, if necessary, re-start themselves automatically.
- Rechargeable storage batteries age more quickly than other types of electrical components; thus it is necessary to pay particular attention to them during routine maintenance work.
- The output and battery capacity in the emergency power supply must be sufficient to move the elevator’s car and to reach the specified landing.
- The emergency power system should be engineered so that the car can be moved either upward or downward for rescue purposes, regardless of the loading situation in the car.

5. Design example

It is first to specify the velocity during the rescue procedure. This value should and will have to be very low so that the power needed for ascent is kept small and additional rotational torques for acceleration are avoided. Normally this speed V_{emerg} will be from 1 - 10% of rated velocity V3. We are taking a value of **V_{emerg} = 0,1m/s**, this means that 10 s will be required to cover 1 m. The travel time monitoring feature in the controls will have to tolerate the long time periods encountered during rescue operation.
The "rescue power output" is then calculated in accordance with the "summation of losses" method. The following information is required here.

- Ascent power during rescue at V_{emerg} — **P_{Aemerg}**
- The Rotor losses in the motor — **P_{lrot}**
- The Stator losses in the motors — **P_{lsta}**
- The iron losses in the motor and other units (inverter, choke rectifier...)

First we calculate the lift performance remembering the article on "Design and planning of elevator systems" (see Lift Report 02/2001" pp. 40ff):

Ascent power

M_{Asc} = $(m_n + m_{car} - m_{cw}) * g * D/2$ (torque at the drive shave)
M_{Asc} = 1471,5 Nm
M_{Amot} = M_{Asc} / i (referenced to the motor shaft division by i)
M_{Amot} = 51,6 Nm
M_{Lmot} = $M_{Amot} * (1/\eta - 1)$ (loss torque referenced to the motor shaft)
M_{Lmot} = 22,1 Nm

$$P_{AEmerg} = \frac{(M_{Amot} + M_{Lmot}) * n_{Emerg}}{9550}$$

Using our parameters of n_n= 1450/min at V_n = 1,6 m/s, the result is n_{Emerg} at V_{Emerg} = 0,1m/s

$$n_{Emerg} = \frac{n_n}{16}$$

P_{AEmerg} = 699 W

Rotor losses

The Rotor losses can be calculated easily - without requiring exact knowledge in the theory of motors or the exact values for the motor's equivalent circuit diagram- using the slip speed n_{sl} and the required torque M. The nominal slip n_{sln} speed can be readily calculated on the basis of the motor's rating data. The following applies to the unit described above:

n_{sln} = 1500/min - 1450/min (at nominal torque M_n = 98 Nm)

n_{sln} = 50/min

Since the relationship between slip speed and torque is linear - good field orientation in the frequency inverter is to take care of this - the slip speed n_{sl} can be calculated at the working point:

$$n_{sl} = \frac{(M_{Amot} + M_{Lmot}) * n_{sln}}{M_n}$$

n_{sl} = 37,6/min

The result is the motor loss, figured by inserting values in the familiar formula:

$$P_{Lrot} = \frac{(M_{Amot} + M_{Lmot}) * n_{sl}}{9550}$$

P_{Lrot} = 290 W

Stator losses

The stator loss is determined on the basis of the winding resistance R_a and the motor current at the above-mentioned working point, applying the following formula:

$$P_{vsta} = 3 * I^2 * R_a$$

In this formula R_a is the winding resistance when the motor is running in a star circuit. If you use a delta circuit the result is $R_a = R_w/3$. It should also be noted that we are assuming here a unit, which is at normal operating temperature, exhibiting winding temperature of 100°C. The motor manufacturer specifies - see the above data for our sample system - $R_a = 0.22\ \Omega$.

$$I = \frac{(M_{Amot} + M_{Lmot}) * I_n}{M_n}$$

P_{Lsta} = 406 W

The total of the individual losses is as follows:

$$P_{AEmerg} + P_{Lrot} + P_{Lsta} = 1395\ W$$

We have not taken account of the iron losses in the motor and the efficiency of the frequency inverter. In the interest of simplification we assume a factor of 1,1 :

P_{Emerg} = 1535 W

Using the UPS specified above, delivering rated effective power P_{wmax} at 2250 W, emergency rescue is possible without limitation as long as no exceptionally high torques are required to break the car loose. For example: 2 times the break-away torque means 2 times the motor current and in turn 4 times the stator and rotor losses.
The calculation scheme used above can be applied in a similar fashion to asynchronous and synchronous gearless lift drives. Naturally, rotor losses do not occur in synchronous gearless drives.
Note: as a rule the UPS will also supply the braking solenoids. In practice the energy, which has to be applied to the brakes - particularly for gearless drives - may be very high (and in the least favourable case can be almost as high as the travel energy itself).

Max. operating period and travel distance during emergency rescue with a UPS
The UPS manufacturer indicates the operating period for various output levels. In our case you will find the following specifications:

Load [VA]	1000	1250	1600	2000	3000
Operating period [min]	26	19	13	10	5

Following the above calculation we choose a loading level of 2000 VA for which we find an operational period of 10 minutes or 600 seconds. During this operating period a maximum distance of 60 m can theoretically be covered at full payload.

Important: Be sure not to forget
- Other using units
- The charge level in the storage batteries
- Aging at the rechargeable batteries, i.e. they lose storage capacity
- The ambient temperature (capacity reduction at low temperatures)

Maximum operating period and travel distance for emergency rescue using the battery cabinet
To calculate the operating period we re quire the discharge current I_b at the battery during emergency rescue and its capacity in Ah. We disregard the voltage drop and calculate on the basis of constant voltage of, for example, 12 V/cell (i. e. U_b = 240VDC).

The power P is calculated with the formula P = I*U, dh I = P/U

$$I_b = \frac{P_{not}\ (1535W)}{U_b\ (240V)}$$

$$\mathbf{I_b = 6{,}4\ A}$$

Using the equitation $t = 3Ah/I_b$ we find a 28-minute operating period for emergency rescue operations (without considering an inverter which might be connected to the battery to supply AC using units).

Important: Be sure not to forget
- Other using units
- The charge level in the storage batteries
- Aging at the rechargeable batteries, i.e. they lose storage capacity
- The ambient temperature (capacity reduction at low temperatures)
- The rated capacity for the rechargeable batteries is specified for a certain discharge period, e.g. 1 hour. The capacity drops if the discharge times are shorter. You will
- find exact information in the battery manufacturer’s specifications (lead-gel, NC-Akku).

6 Estimating the power required for rescue

Very exact specifications are required for the above calculation, data that will often not be available at all during the bidding phase. In this case one can apply the following argument to estimate the requirements:

- Ascent power during rescue at V_{Emerg} -> $\mathbf{P_{AEmerg}}$ will be from 5.-. 10% of installed motor power. (please determine this as closely as possible)
- The efficiency η_{mot} of the driving unit will lie between 0,75-0,95 !

Adding the lift power and the motor losses makes it possible to arrive at a simplified estimate for rescue performance. Experience has shown that it will lie at a value of from 15. - 25% of the installed or projected motor power.
If you are manufacturer of standard systems, then you can naturally measure the power drawn by an existing system at emergency rescue speed of V_{emerg} . One does not even need an emergency power supply for this purpose since the power can be measured at the line input to the frequency inverter without encountering any great error. The measurement instrument will have to register the effective values for voltage U between the phases and the phase current I at rectifier load ($P=\sqrt{3}*U*I$). To make this measurement, travel speed will have to be set to match the planned emergency rescue velocity.

7 Summery

The power required for emergency rescue can be estimated fairly accurately an easily if the motor losses can be calculated. This is in fact the case for frequency inverters using field-oriented control and a motor encoder. Other regulation and open loop control systems have no way to monitor motor slip, particularly at the slow motor speed desired here. Motor current in this case can rise expectedly, the break-down slip frequency is reached, and all the output of the UPS is consumed as losses in the stator and rotor without any relevant torque being available. Elevator system functioning is then left to chance (e.g. the being warm or cold).

Gearless synchronous motors, asynchronous motors and upgrading existing systems

- Calculations for synchronous can be made as described above. Thanks to the permanent magnets in the rotor, both slip and rotor losses are eliminated.
  Important: Be sure to take into account her the "poor" efficiency level which these devices exhibit under certain circumstance (due to their physical size and high number of poles).
- Gearless asynchronous winding units are engineered in a fashion similar to the calculation scheme described above.
  Important: Be sure to consider the relatively high no load current for this type of unit; it results from the physical size and the large number of poles.
- Silumin-rotors (in the event of modernization), i.e. motors with "soft" operating characteristics, which are retained in existing systems (previously set up for pole switching, with multi-speed windings or optimised for thyristor voltage control) are not suitable at least for emergency rescue with a UPS. Here, as an exception to rule, the motor should not be left in service.