# Dynamic Lift Control for Improvements in Energy Efficiency

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**Abstract.** A lift's energy behaviour is an important issue and R&D departments are constantly searching for ways to improve results. Focusing on the electrical-electronic area, it is already well-known that the use of 3VF inverters and PMSM motors allows better energy results to be achieved. The combined use of real-time communications between lift control and inverter and the use of "direct approach to floor" function (we suggest to call this feature Direct To Floor in the paper) allows the realisation of an energy decision-making control panel and improvements to traditional energy consumption. From this point onwards, our objective is to present an improved concept for energy-efficiency based on the development of a new dynamic control. To achieve this, the following is important: 1 - Identify the different behaviours of the lift with regard to energy-efficiency in each different stage of the journey, taking into account: the number of people travelling, the direction of travel, the distance to be travelled and the lift's speed. 2 - Propose energy-saving improvements for each stage, always using DTF & sharing information in real time as a basis. 3 - Develop an intelligent control capable of taking decisions affecting energy-efficiency in real time. This allows the best energy-saving profile to be selected for each journey, adapting the curves as well as the motor and brake control in any situation. 4 - Using a certain energy profile and incorporating a certain set of proposals can produce good results in some circumstances and only acceptable results in others. For this reason, the smart lift control must always select the most suitable option. 5 - Show a comparative analysis of the results obtained with the Smart-ECO mode with traditional solutions, as well as a comparison with current regenerative systems. In this paper, results with ISO25745-2:2015 are also shown. The aim of this paper is to make an in-depth presentation of the studies carried out for the journey stages, the proposals and the obtained results. All the results shown have been taken from real lift installations.

## 1 INTRODUCTION

Given the increasing importance of energy efficiency to the lift sector, there is already a large number of studies and reports on this subject, of which we reference some of the best-known [1,2,3,4,5,6,7]. There are also several kinematic analyses, such as [8,9]. To date however, we have found no papers with the concentrated focus on energy efficiency which we are offering here.

What we set out to do was to analyse the energetic behaviour of a traction lift with a gearless permanent-magnet synchronous motor (PMSM) during the various stages of its travel, starting with analysis of its performance in DTF (Direct To Floor or Direct Approach) mode. In [10] we present evidence of greater energy-saving in DTF mode as compared to that achieved with the traditional speed curve profile and the standard approach speed.

All our data was generated by tests carried out in our testing tower, using a lift system with a travel distance of 15.31 metres, a 1000 Kg lift car, a gearless PMSM, a 2:1 roping ratio, 50% counterweighting and a compensation chain, at a travel speed of 1 metre per second.

We carried out several hundred tests (511 measurements), taking measurements with a FLUKE 435 II Power Quality & Energy Analyzer and software applications for 3VF frequency inverters which included NCDrive trace and precision data logging functions[11].

Our first step was to carry out tests to measure the energetic behaviour of the lift under different conditions, using the following variables: the number of passengers inside the lift car, the speed reached during the journey, the direction of travel and the distance travelled. We also used the motor with different standard control settings to see how each one affected the amount of energy consumed.

Once we had recorded the detailed variations in the lift's energetic behaviour, we tested out different speed curve settings and various electrical configurations aimed at lowering energy consumption, while at all times maintaining the optimum passenger ride comfort, thereby generating an extensive database produced by the settings and configurations for each individual journey type.

With the energy consumption improvements achieved, we created a simulator which allows us to configure the lift traffic in different types of buildings and during different time periods. This simulator enables us to predict energy consumption by each particular lift system.

Using real-time communications (RTC) and the Direct Approach mode, our aim is to develop an intelligent lift control system that, right before the start of the journey, can use the detailed data mentioned above to select the most energy-efficient consumption profile to carry out the required task.

We have also calculated the impact that these improvements could have on lift system rating according to ISO 25745-2.

We carried out tests to analyse the lift's energy efficiency when fitted with a regenerative drive system (a regenerative kit very easy to connect to the control panel) which feeds electricity back into the building's power grid, using an up-to-the-minute device produced by a European firm with an excellent reputation in the lift sector. The resulting data was incorporated into our simulator system.

## 2 OVERALL APPROACH

During lift travel, electricity is consumed by the control system itself as it manages the functioning of the lift and also by the traction machine with energy wasted in the brakes and by the motor itself. Given this, as a general rule less travel time implies less waste of energy by the inverter and the motor as well as by the control system.

However it is not always the case that a shorter travel time will result in energy-saving, because it may be accompanied by increased energy use despite the reduced time frame.

### 2.1 Phase 1: Control system at 0 hz: motor start-up, brake release & control of roll-back (rb) effect

During this phase, it is important to avoid causing unnecessary delays, given that they waste energy, and to ensure a smooth and comfortable start-up.

A PMSM does not consume active electric power until it is required to generate torque. One option in the 0 Hz phase is to control the start-up based in induction motors control (using the magnetisation times that these motors require). This reactive power is not present at the lift's connection to the mains, but the consequent activation of the control system and the frequency inverter does lead to energy wastage. Dispensing with this period would therefore save energy. Fig.1, note 1 in the text.

Once the brake release command, MecBrakeOpen at Fig.1 in the text, is delivered, the rotor is unlocked and it is crucial that the system accurately determines the exact degree of torque to be applied immediately in order to avoid any RB effect.

Irrespective of the direction of travel, the drive unit will always consume electrical power proportionate to the difference between the lift car and the counterweight loads (Fig.1, note 2 in the text.)

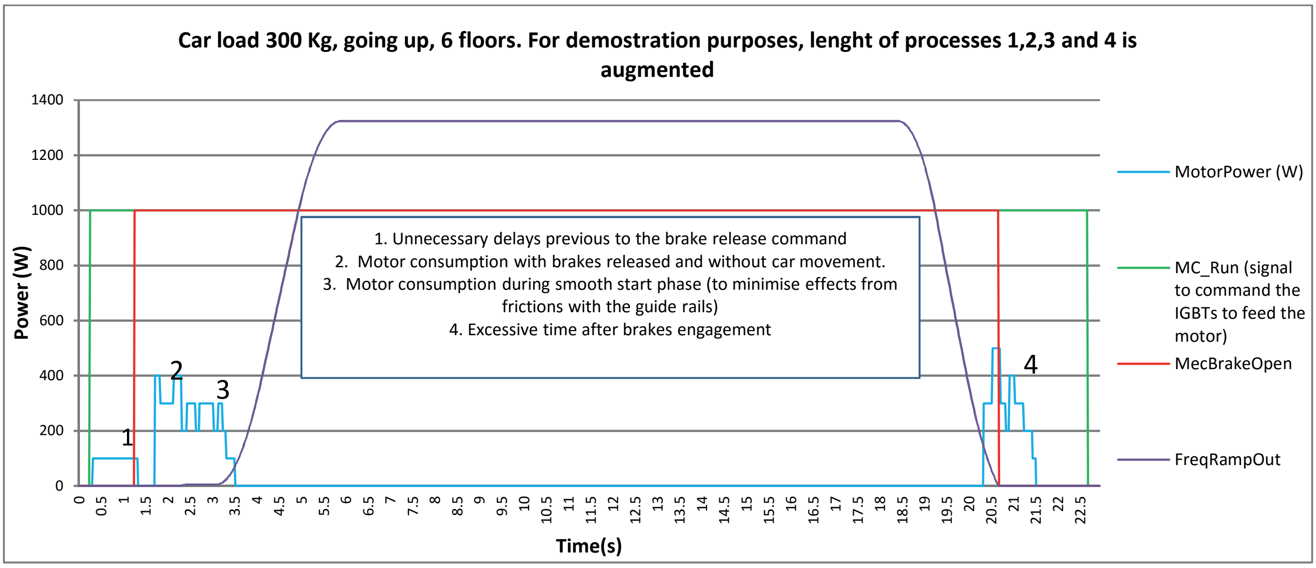

**Figure 1. Lift going up, 6 floors, car load 300 kg.**

It is well-known in the lift industry that to control the RB effect, a weighting device in communication with the control system can be an effective solution, although depending on its mechanical design and in-car load placement, this could be a not very accurate operation.

An alternative way: The control of the brake release time. It is good practice to control this using brake switches in order to determine the exact motor setting required to avert the RB effect.

Both solutions (weighting device and brake switches) have an added cost. A slight increase in electric power consumption is produced with the weighting device option (significant when the lift is idle or on standby). Brake switches, unless they are inductive, tend to experience malfunctions that cause unnecessary energy usage.

Once the rotor is completely unlocked, it is essential to terminate the 0 Hz control phase (Fig.1, notes 1 and 2 in the text) and initiate a smooth start-up speed curve (Fig.1, note 3 in the text).

Reducing the duration of 0Hz phase is significant because 1) it reduces travel time and improves ride comfort, and 2) it cuts down the time spent generating wastage (Fig.1, note 3 in the text).

Energy-saving proposal: to detect and interpret (without brakes switches and without weighting device) the electrical variables in the motor as well as the encoder signals, and determine the precise degree to torque required.

The study of the electrical variables also enables us to calculate optimum brake release timing at any moment (as this can also change).

A fast and accurate energy-supply response avoids unnecessary delays in PMSM operation. As soon as the brake has been released, the smooth start-up phase must begin immediately.

## 2.2 Phase 2: Smooth start-up at low speed

Potential disturbances in the ride comfort, because of any possible mechanical frictions on the guide rails, are minimized leaving the floor at low speed during a brief period of time.

The energy consumption depends on the difference between car load and the counterweight balance, without taking into account any losses because of the mechanical and electrical efficiencies. Independently of the in-car load, this phase always involves energy consumption. Even when the motor is operating in generative mode, mechanical and electrical wastage in the system obliges the 3VF inverter to feed in electrical power.

Energy-saving proposal: In this phase as well, the time taken to execute a smooth start-up must be cut to a minimum, while guaranteeing ride comfort. The shorter the phase, the more efficient it is.

It is important that this phase is designed specifically to suit the specific mechanical characteristics of the particular lift system. Otherwise there will be small travel delays and higher energy consumption, with no improvements in ride comfort (Fig1, note 3 in the text).

## 2.3 Phase 3: Acceleration curve (initial jerk, or jerk 1 → constant acceleration ramp → second jerk, or jerk 2 to achieve constant speed)

As is well-known, the lift's energy consumption is directly proportional to the torque produced during the acceleration ramp.

### 2.3.1 Journeys where the motor works in generative mode

During the acceleration phase, the motor can achieve generative mode either very shortly after ramp start-up or later on. Also, sometimes the motor can alternate between generative and motor modes during the acceleration ramp. This produce different energy profiles even when the acceleration curve is exactly the same, depending on the load in the car.

Both Fig.2 and Table 1 in the text show how the motor's electricity demand has a direct relationship with the in-car loading (both the peaks in consumption and the form of the fluctuations).

Fig. 2 in the text shows the power demand to the mains when the lift is going up and the counterweight is heavier than the car. The area created under the power curve is the electrical energy used. It is seen that the lift reaches the generative mode (and no electrical energy is demanded any longer by the motor) when the power becomes stable to 600 W.

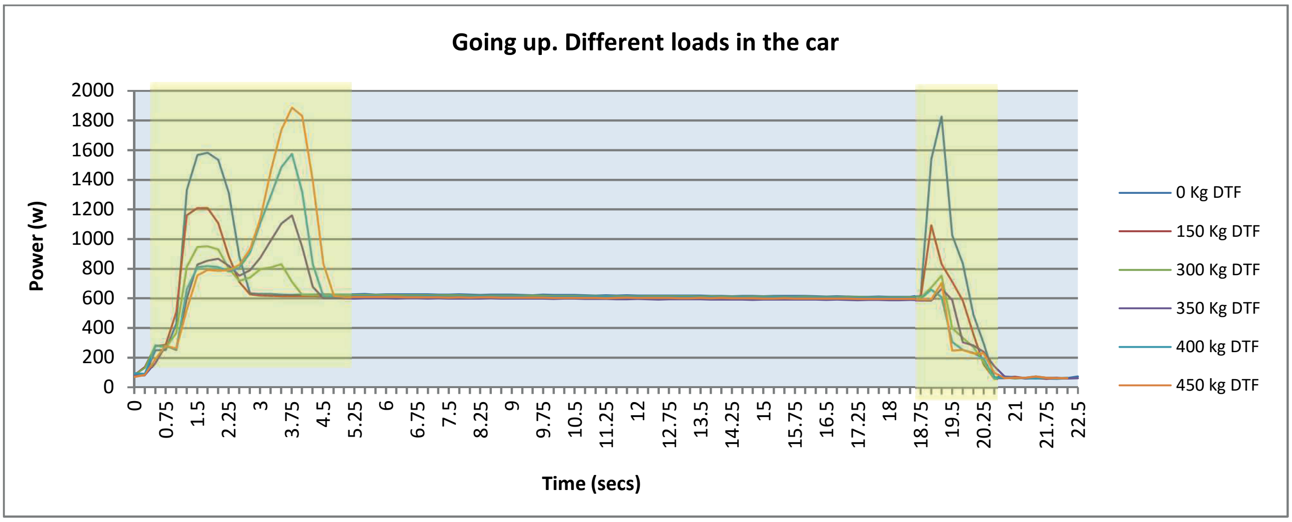

**Figure 2.Going up with different loads in the car (Measurement taken at connection to the mains).** ***For clarity's sake, the timer to feed the brakes at 200/100 volts has been switched off. They were connected to 200 VDC during the complete journey. Real power consumption is lower.***

**Table 1: Time to achieve performance as generator**

| Nominal load : 1000 [kg], upwards travel, Accel. = 0.55[m/s$^2$], Jerk1= [0.55m/s3] | Time elapsed since start of car movement until electrical power supply to motor ceases (measured from frequency inverter output) |
|---|---|
| 0 [kg] | 1.679[ms] |
| 150 [kg] | 1.748[ms] |
| 300 [kg] | 2.702[ms] |
| 450 [kg] | 3.449 [ms] |

So, it is shown how the time (Table 1 in the text) and the energy profile to reach this generative mode depend on the car load. During this period, the motor is demanding electrical energy from the mains.

On the same acceleration ramp, the lesser the difference between car and counterweight loading, the longer this period lasts.

Energy-saving proposal: Generally speaking, in terms of reducing electricity consumption, the motor should achieve electricity production capability (generation mode) as soon as possible; although, when the car/counterweight load difference is very small, we occasionally observe the opposite effect (we analyze this later in the paper). Of course, the acceleration and jerk values must keep the ride into the levels of comfort already well-known in the lift industry.

In the majority of cases, the electrical energy generated by the motor will simply be converted into heat by the brake resistor. However, the lift will have made its journey drawing less electrical energy from the mains supply.

### 2.3.2 More detailed observations: car loads between 30 & 45% (ascending) and 55 & 70% (descending)

From 300 Kg upwards, the lift tested required electrical energy almost until only just before it reached its nominal speed.

Energy-saving proposal: in this case, reducing the rate of acceleration results in the motor generating its own electrical energy earlier and without causing significant increases in journey time. During a journey of 15.31 metres at 1m/s, the consequent delay is less than half a second (Fig.3 in the text).

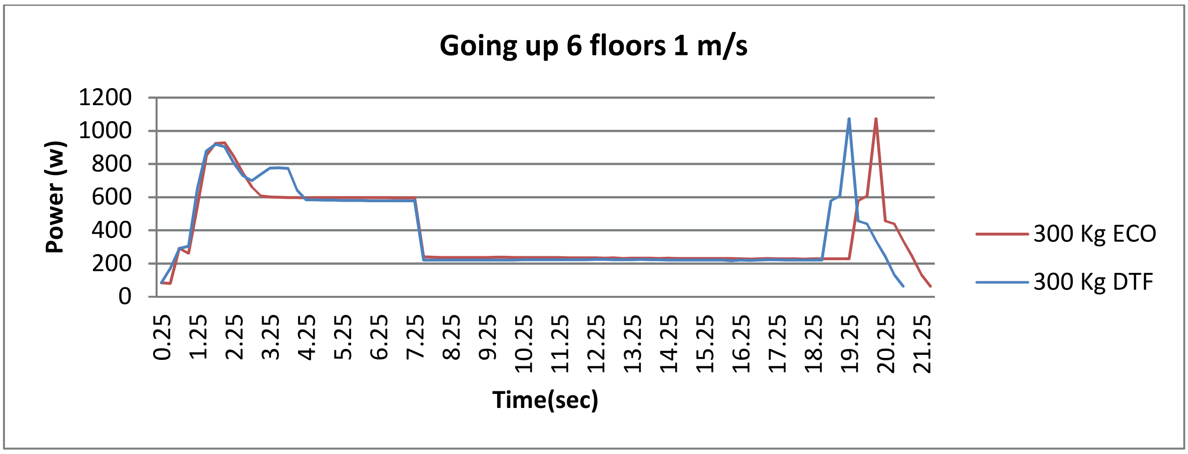

**Figure 3. Areas under the power curves represent the electrical energy demand. This Fig. shows how energy generation begins earlier (about 1.5 s earlier approx.) and energy consumption is reduced if ECO profile is used.** ***For clarity's sake, the timer to feed the brakes at 200/100 volts was configured to keep the brakes at 200 VDC during 7 seconds approx. Real power consumption is lower. Because of this, the power in the graph goes down beyond instant 7.25 sec.***

When the loading difference between the car and the counterweight is even smaller, modifying the Jerk2 (from constant accel. ramp to constant speed) value and reducing the rate of acceleration, results in the motor's generation of electrical energy being delayed even longer, rather than starting earlier.

However, this also results in a reduction in the lift's energy consumption (Fig. 4 in the text).

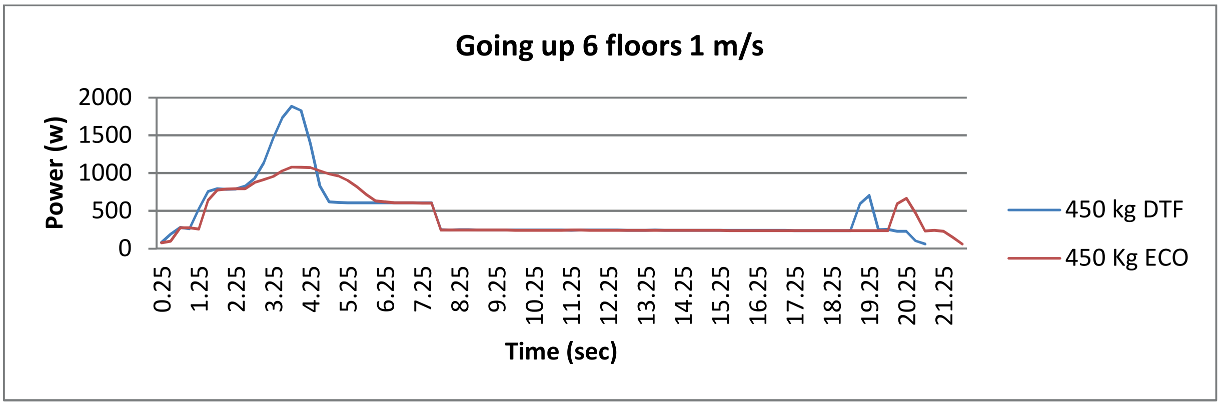

**Figure 4. Areas under the power curves represent the electrical energy demand. It is shown how energy generation begins later (about 1 s later approx.) using the ECO profile.** ***For clarity's sake, the timer to feed the brakes at 200/100 volts was configured to keep the brakes at 200 VDC during 7 seconds approx. Real power consumption is lower. Because of this, the power in the graph goes down beyond instant 7.25 sec.***

Energy-saving proposal: Acceleration and Jerk2 have to be selected at appoint that journey time is not prolonged too much. Also this would increase electricity wastage and energy consumption rather than reduce it.

### 2.3.3 Journeys with the traction machine working in motor mode

We found some acceleration and jerk values which, while always maintaining the levels of ride comfort standard in the industry, allowed us to adjust the travel time and reduce power wastage.

Differences for the selected values exist depending on the loads in the car and speed to be achieved.

Exceeding these values (in addition to having an unacceptable effect on ride comfort) sometimes resulted in higher energy consumption despite the shorter journey time, and going below them also led to increased consumption.

## 2.4 Travel Velocity: Surpassing motor's rated speed by up to 20%

In [10] we explain how, thanks to real-time communication (RTC) between the control system and the 3VF frequency inverter, the rated speed of the motor can be surpassed when the imbalance between car and counterweight loading is not at its maximum. This cuts travel time, which in turn reduces energy wastage.

Reaching a travel speed above and beyond the lift's rated speed requires the delivery of greater kinetic energy, which generally results in increased energy consumption until that particular higher speed is reached.

Thanks to RTC, the control system can select a particular speed at the start of the journey on the basis that it is the most energy-efficient. In order to do so, given that kinetic energy is a function of mass and velocity, it has to evaluate the distance to be travelled and the load to be carried. The decision to exceed rated speed during the journey is only justifiable in energy terms when the distance to be travelled is far enough to mean that the savings in energy wastage are greater than the initial expenditure in energy supply.

## 2.5 Phase 4: Car-to-landing approach manoeuvre & approach speed

Fig. 5 in the text, taken from [10], reveals that, when not in DTF mode, the motor starts to consume electricity as soon as approach speed is reached. This is always the case, independently of the in-car load and of the direction of travel.

DTF mode overrides the standard approach speed, results in faster journey times and so the lift spends less time generating wastage (in the control system, brakes and motor).

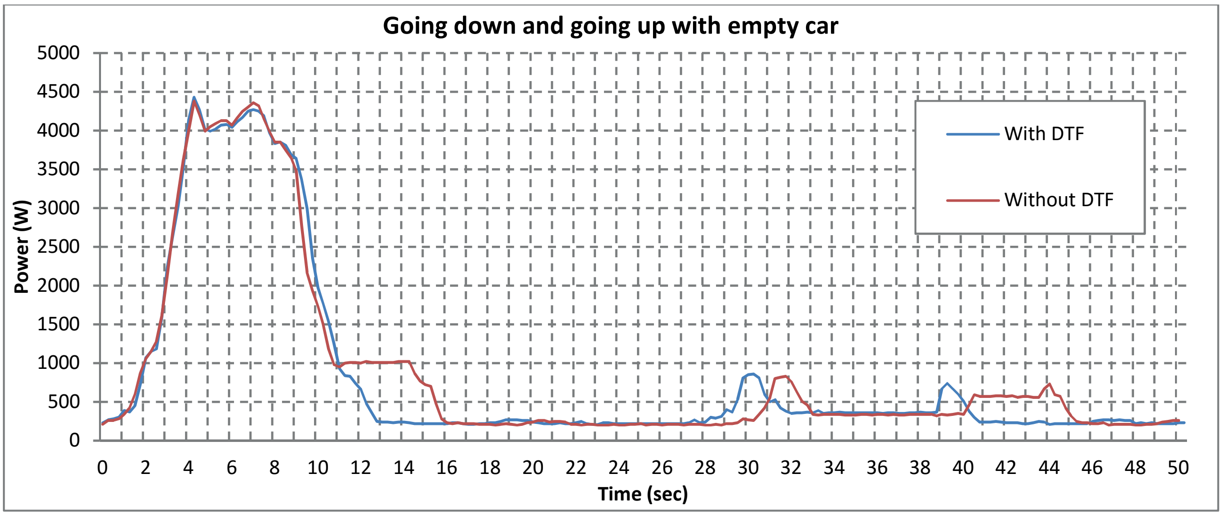

Figure 5. Lift going down and going up with empty car.

### 2.6 Phase 5: Arrival at stop: jerk4 (from constant deceleration to 0 hz), 0 hz phase & demagnetisation of motor

Fig. 6 in the text shows that when the lift reaches speeds approaching 0 Hz, the motor always consumes electricity, even if it has been operating in generative mode throughout the rest of its journey.

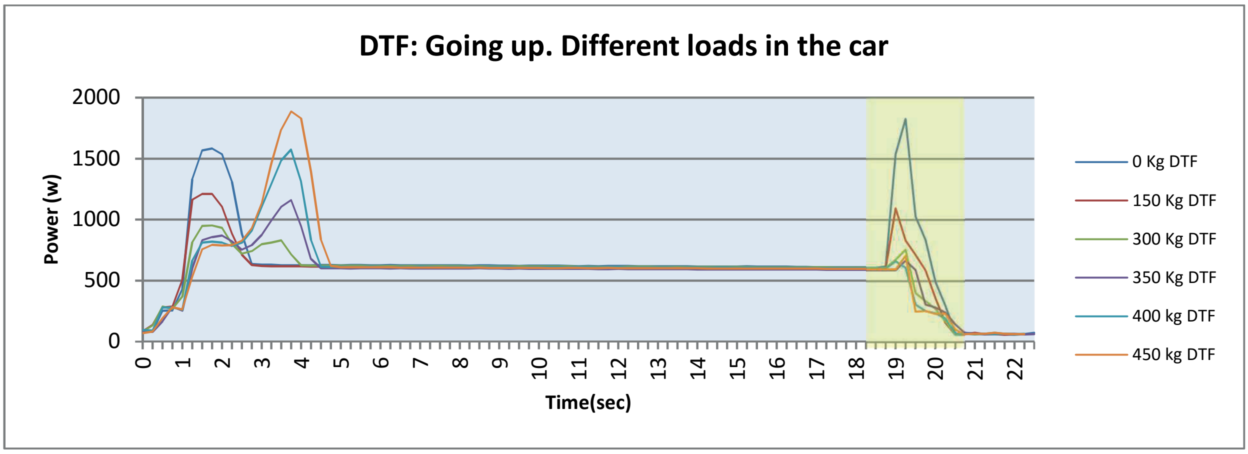

**Figure 6. 1000 Kg lift, at 1m/s, ascending. Measurement at connection to the mains.** ***For clarity's sake, the timer to feed the brakes at 200/100 volts has been switched off. They were connected to 200 VDC during the complete journey. Real power consumption is lower.***

Also, for a few moments supply to the motor remains at 0 Hz, both before and after the brakes are switched off. See also Fig.1, note 4 in the text.

One way of achieving energy savings is to reduce the duration of this phase to an absolute minimum without interfering with ride comfort. Once the brake is blocking rotor movement, it is reasonable to start to demagnetize. To do this efficiently, it is very important to identify the exact timing of brake engagement.

Fig. 6 in the text also shows how consumption is conditioned by car/counterweight load imbalance.

So it is vital to reduce this phase to a minimum, but it is counterproductive to make the cut in power too abrupt, as this can make motor operation too noisy.

## 3 RESULTS

After carrying out hundreds of controlled tests, we have developed speed curve profiles and sets of electrical adjustments which correspond to each of the phases described above: according to percentages of rated load (0%, 15%, 30%, 45%, 55%, 70%, 85% or 100%), according to direction of travel (upwards or downwards), according to the number of stops (2, 3, 4, 5 or 6) and according to the speed of travel (1m/s, or 1.2m/s where this is possible).

For reasons of space in this paper, here we will present only the energy expenditure and savings recorded (real measurements) for journeys of two stops (6.31 metres) and six stops (15.31 metres).

Table 2. Energy expenditure and savings identified for journeys of two stops and six stops.

| | Energy demand (Wh) | | | | | | Savings (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Approach speed (0.05 m/s) | | DTF | | Dymamic control | | DTF Vs Approach speed | | Dynamic control Vs Approach speed | |
| [kg] | Up [Wh] | Dw[Wh] | Up[Wh] | Dw[Wh] | Up[Wh] | Dw[Wh] | Up (%) | Dw (%) | Up (%) | Dw (%) |
| 6 floors | | | | | | | | | | |
| 0 | 3.336 | 30.422 | 2.154 | 29.592 | 1.971 | 29.292 | 35.432 | 2.728 | 40.917 | 3.714 |
| 150 | 2.739 | 21.793 | 1.981 | 21.338 | 1.624 | 20.966 | 27.674 | 2.088 | 40.708 | 3.795 |
| 300 | 2.371 | 13.75 | 1.882 | 13.572 | 1.59 | 13.01 | 20.624 | 1.295 | 32.940 | 5.382 |
| 450 | 2.611 | 7.036 | 2.166 | 6.982 | 2.005 | 6.825 | 17.043 | 0.767 | 23.209 | 2.999 |
| 550 | 7.036 | 2.611 | 6.982 | 2.166 | 6.825 | 2.005 | 0.767 | 17.043 | 2.999 | 23.209 |
| 700 | 13.75 | 2.371 | 13.572 | 1.882 | 13.01 | 1.59 | 1.295 | 20.624 | 5.382 | 32.940 |
| 850 | 21.793 | 2.739 | 21.338 | 1.981 | 20.966 | 1.624 | 2.088 | 27.674 | 3.795 | 40.708 |
| 1000 | 30.422 | 3.336 | 29.592 | 2.154 | 29.292 | 1.971 | 2.728 | 35.432 | 3.714 | 40.917 |
| 2 floors | | | | | | | | | | |
| 0 | 2.477 | 8.303 | 1.357 | 7.500 | 1.171 | 7.215 | 45.216 | 9.671 | 52.725 | 13.104 |
| 150 | 1.857 | 5.921 | 1.132 | 5.436 | 0.943 | 5.297 | 39.041 | 8.191 | 49.219 | 10.539 |
| 300 | 1.516 | 3.835 | 1.025 | 3.589 | 0.903 | 3.656 | 32.388 | 6.415 | 40.435 | 4.668 |
| 450 | 1.742 | 2.329 | 1.320 | 2.218 | 1.194 | 2.278 | 24.225 | 4.766 | 31.458 | 2.190 |
| 550 | 2.329 | 1.742 | 2.218 | 1.32 | 2.278 | 1.194 | 4.766 | 24.225 | 2.190 | 31.458 |
| 700 | 3.835 | 1.516 | 3.589 | 1.025 | 3.656 | 0.903 | 6.415 | 32.388 | 4.668 | 40.435 |
| 850 | 5.921 | 1.857 | 5.436 | 1.132 | 5.297 | 0.943 | 8.191 | 39.041 | 10.539 | 49.219 |
| 1000 | 8.303 | 2.477 | 7.5 | 1.357 | 7.215 | 1.171 | 9.671 | 45.216 | 13.104 | 52.725 |

## 3.1 Simulating traffic types: results obtained

We created a simulation programme which uses the extensive database generated by the tests to select the optimum energy-use configuration for each specific type of journey, taking the following factors into account: travel distance, number of passengers on board and direction of travel. In each case, right at the start of the journey, the control system recommends a specific energy use profile.

Some of the simulated traffic types are dealt with below. We decided not to apply the standard traffic type definitions used in articles, studies and simulation software in the lift sector.

The sequences and the journeys defined in this chapter are achievable, thus they have been studied and the results are shown. However, we haven't dedicated time to use definitions and traffic simulations that are defined and explained in very well-known books such as [12,13,14].

We are fully aware of them and a comparison of our differences in criteria may well be the subject of a future study. But the results achieved by our simulator have been notably effective.

Note: As it is not the purpose of this paper, these examples does not show energy consumption during idles and standby periods.

**Example A:** High-traffic lift in a metro station. 2 stops, 2000 journeys/day, 12.31 metres travel distance, 1000 kg, 2:1, gearless PMSM, 50% counterweight:

Percentage of journeys depending on the car loading (example: 28% of the 2000 journeys are made with 450 kg in the car): 0 kg: 2%, 150 kg:4 %, 300 kg: 10%, 450 kg: 28%, 550 kg: 28%, 700 kg: 18%, 850 kg: 6%, 1000 kg: 4%.

Power consumption per day: standard system: 12.09 kWh.

Power consumption per day: proposed dynamic control: 11.02 kWh→8.86% saving.

**Example B:** Low-traffic lift in residential building. 6 stops, 15.31 metres travel distance, 1000 Kg, 2:1, gearless PMSM, 50% counterweight:

We randomly generated the following sequence of journeys in a low-traffic context:

Lift on Floor 0. Empty→Called to Floor 5 (empty).→4 passengers board.→Called to Floor 2.→2 passengers board (6 now in car).→Travels to Floor 0.→Waits empty on Floor 0.→2 passengers board to travel to Floor 5.→Lift ascends to Floor 5. →2 passengers get out. →Waits empty on Floor 5.→2 passengers board.→Lift travels to Floor 4 where 2 passengers board (4 now in car).→Lift travels to Floor 0. →Lift waits empty on Floor 0. →4 passengers board.→2 get out on Floor 4.→2 get out on Floor 5.→End.

**Table 3.Example B: consumptions and savings.**

| Traffic example B | Magnets (standard approach speed) [Wh] | DTF [Wh] | Dynamic solution [Wh] |
|---|---|---|---|
| Ascent from ground to 5th (empty) | 3.336 | 2.260 | 1.971 |
| Descent from 5th to 2nd (4 passengers) | 8.585 | 8.579 | 8.367 |
| Descent from 2nd to 0 (6 passengers) | 3.510 | 3.413 | 3.291 |
| Ascent from 0 to 5th (2 passengers) | 2.739 | 1.981 | 1.562 |
| Descent from 5th to 4th (2 passengers) | 5.921 | 5.436 | 5.125 |
| Descent from 4th to 0 (4 passengers) | 11.268 | 11.075 | 10.809 |
| Ascent from 0 to 4th (4 passengers) | 2.156 | 1.668 | 1.476 |
| Ascent from 4th to 5th (2 passengers) | 1.857 | 1.132 | 0.902 |
| TOTAL [Wh] | 39.372 | 35.544 | 33.512 |
| **Energy saving (%)** | - | **9.7** | **14.9** |

**Example C:** *(includes results from tests using the regenerative drive system):* Medium-traffic lift in hospital, 5 stops, 1000 journeys/day, 12.31 metres travel distance, 1000 Kg, 2:1, gearless PMSM, 50% counterweight.

Journeys (ascents, 40% of total): 0 Kg: 15%, 150 Kg: 25%, 300 Kg: 25%, 450 Kg: 15%, 550 Kg:10%, 700 Kg: 7%, 850 Kg: 2%, 1000 Kg: 1%.

Journeys (descents, 60% of total): 0 Kg: 5%, 150 Kg:18%, 300 Kg: 24%, 450 Kg: 19%, 550 Kg: 15%, 700 Kg: 14%, 850 Kg: 3%, 1000 Kg: 2%.

Journeys 2 stops: 40%, Journeys 3 stops: 30%, Journeys 4 stops: 20%, Journeys 5 stops: 10%.

Daily power consumption–standard solution: 4.30 kWh/day

Daily power consumption–dynamic solution: 3.65 kWh/day - **14.82% saving**

Daily power consumption-**REGEN** but without dynamic solution: 3.00 kWh/day - **30.04% saving**

## 3.2 The regenerative drive system tested

The measurements with the FLUKE 435 II were taken at the regenerative unit power terminals. The savings figures were reached by subtracting the energy generated from the energy consumed. The lift's energy consumption when on standby and in motor mode was greater with this unit connected to the lift. During the time the unit does not produce electrical energy - it gets constantly 40 W. Also, in standby mode, it needs to get 10 W constantly. So, the tested lift passed from 33W to 43 W in this mode.

The electric energy generated by the lift was fed into the building's power grid, which begs the question: where exactly did that energy go? The answer to that is not at all clear. It is dependent on various factors.

A small amount of the energy was probably consumed by the lift system itself - by the lift car lighting, the control system and the brakes, for example. Whatever remained was fed into the building's grid and, depending on the specific characteristics of its wiring network and of the electrical devices connected to it at the time and their particular impedance, the energy may have been consumed within the building or otherwise used outside it.

In terms of energy consumption within the building, depending on exactly where the electricity meter is located, it is entirely possible that the electricity produced by the lift was actually charged for by the power company, without taking into account that that energy was produced by the lift, and not by the power company. Nowadays, it is very rare that a bi-directional meter is installed.

While ignoring for the moment the high costs of a regenerative solution, our proposed innovation (the dynamic control) poses the question as to whether or not working on “CONSUMING LESS ENERGY” makes more sense than consuming energy but “PRODUCING A SMALL AMOUNT OF ENERGY” (without assuring how and who will use it).

### 3.3 Implications of compliance with ISO 25745-2

We decided to run comparative tests using the criteria laid out in ISO 25745-2, now widely accepted in the lift industry. Its chapter 4, which deals with data collection and analysis tools, explains how to use the reference cycle set out in ISO 25745-1. So the measurements were taken with the car empty, taking the profile seen as the best energy-saving option from the suggested dynamic control previously identified. Also, at no point did the travel speed exceed 1m/s - the motor's rated speed.

In this paper we have shown energy savings achieved in all journey types. These results improves the efficiency depending on the car loading and distance travelled. Given that ISO classification is based on the reference cycle, here we can only show energy-saving improvements in one particular instance - when the car is empty.As a result, we can only regard the data which appears in the corresponding table as indicative, rather than definitive.

**Table 4. Savings and improvements produced by the suggested solution are shown.Terms defined by ISO 25745-2: $E_{rd}$: daily running energy consumption [Wh], $E_{nr}$: daily non running (idle/standby) energy consumption [Wh], $E_{d}$: total daily energy consumption [Wh], $E_{y}$: annual energy consumption [kWh].**

| Data inputs to the ISO calculator | | | |
|---|---|---|---|
| | Approac. Speed 0,05 m/s | DTF | Dynamic |
| Number stops | 6 | | |
| E. cycle ref. | 34.558 | 32.546 | 32.062 |
| E. short cycle | 17.327 | 15.376 | 14.902 |
| Load | 1000 [kg] | | |
| Speed | 1[ m/s] | | |
| Power idle | 50[W] | | |
| Power 5 min | 33[W] | | |
| Power 30 min | 33[W] | | |

| Results | 700 journeys, Cat. Use 4 | | | 110 journeys. Cat. Use 2 | | |
|---|---|---|---|---|---|---|
| | Approac. Speed 0,05 m/s | DTF | Dynamic | Approac. Speed 0,05 m/s | DTF | Dynamic |
| Journey energy, $E_{rd}$[Wh] | 5852.8 | 5235.7 | 5085.9 | 1017.6 | 917.77 | 893.55 |
| Class | 3 | 3 | 3 | 3 | 3 | 3 |
| Stop energy, $E_{nr}$[Wh] | 832.39 | 832.39 | 833.6 | 864.55 | 864.55 | 864.72 |
| Class standby | 1 | 1 | 1 | 1 | 1 | 1 |
| Energy day, $E_{d}$[Wh] | 6685.1 | 6068.1 | 5919.5 | 1882.2 | 1782.3 | 1758.3 |
| Energy year $E_{y}$,[kWh] | 2440.1 | 2214.9 | 2160.6 | 687 | 650.5 | 641.8 |
| Class | **C** | **C** | **B** | **B** | **B** | **A** |

In both cases studied, and working in the same conditions, a lift could achieve a better energy classification if the dynamic solution is implemented.

## 4 CONCLUSIONS

On the basis of the improvements in the lift's energy efficiency in each type of journey which we have identified in this paper, we now propose the development of an intelligent control system which can take effective energy-saving decisions (adjusting the acceleration and speed curve profiles and motor control variables) immediately prior to start-up, while always keeping passenger comfort and travel time as a clear priority.

The Direct To Floor curve is clearly a fundamental starting point, and real-time communication between control system and inverter is demonstrably essential to the achievement of the purposed goal.

With these two keys available (and the use of PMSM motors), the solution shown in this paper is developed as a software programme that adds intelligence to the system in order to control in an energy efficient way the speed curve of the journey as well as motor control variables. Thus, no additional hardware components are required (taking into account a good capacity of the microprocessors and big enough storage spaces in the electronic boards).

We raise concerns about the use of the electrical energy produced by a regenerative drive system. We pose the question as to whether or not consuming less energy makes more sense than producing a small amount of energy. In certain buildings, the installation of lifts which are genuinely efficient in their energy use may well be a more interesting energy-saving measure than installing a regenerative lift system.

It has become more and more common in various markets to see regenerative lifts with small cars and a rated speed of 1m/s installed in buildings with low traffic intensity. Under such conditions, it may well be the case that a lift as the one we propose would constitute a more interesting and economic solution.

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## BIOGRAPHICAL DETAILS

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