Improving the Energy Efficiency of Lifts

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Abstract: Obtaining the highest possible energy efficiency of a lift has been a challenge in the industry in the past years and remains so. As an electro-mechanic system, the lift has two areas of possible design improvement. Nowadays, in the electrical arena, the use of certain components and their control help to achieve an efficient performance: PMSM motors, 3VF inverters, regenerative systems, LED lighting, standby mode, etc. Nevertheless, we have identified two ways to further improve the efficiency. The first one is to add intelligence to the lift control, especially related to energy related issues. The second line of action is to further improve the energy reuse when the motor is generating. This is achieved by storing energy rather than just regenerating the energy to the grid.

1 INTRODUCTION

1.1 Starting point

Nowadays, the mechanical designs used for lifts and the use of materials, such as high-strength steel, has contributed to the improvement of energy efficiency.

With regards to the electrical package, new components and features such as those stated previously, have led to a significant improvement. The energy impact of lifts in their service life has been reduced considerably.

Taking into account the levels achieved, we present a new approach which will allow further improvements to be achieved. In this section of the introduction, there are three points to be taken into account due to the fact that they are dealt with in this paper. They are shown below together with a brief description and some of their advantages (some of them are already well-known in the lift industry). Point 1.2, “real time communications”, is important for the development of point 1.3 (“Direct to Floor system”) and to obtain other features detailed later in the paper. Point 1.3 is the starting point to achieve point 1.4

The objective of this paper is to focus on the energy improvements which are obtained thanks to the application of the three points (1.2, 1.3 y 1.4) such as the use of energy storage systems. This will be shown from chapter 2 onwards.

1.2 Real time communications

Developments in real time communication between the lift controller and other electronic devices allow significant amounts of information to be shared. In this way, the electronic controller can make many decisions. For example, this is important in order to develop a DTF solution which does not require the traditional second encoder to control the car position in the shaft (already known in the lift industry) as well as to obtain a call designation system in a DTF lift that only uses the motor encoder readings. Here, the real-time communication between the lift controller and 3VF inverter is fundamental for both devices (this DTF solution is shown in 1.3).

Other decisions can directly affect the energy efficiency of the lift. For this reason, the constant communication between the controller, the 3VF frequency inverter and the energy recovery system is fundamental. This paper focuses on this subject. Further on, we will look at how the communications allow working modes which can improve the energy efficiency.

Some examples:

1.2.1. In the lift controller, to know the state of the 3VF inverter (without using digital I/O) allows us to know the temperature of the IGBTs and confirm that this is correct before switching it off in order to avoid reducing their lifetime. More details in chapter 4.

1.2.2. In a DTF solution without the traditional second encoder, the 3VF inverter, when switched back on (leaving standby mode with the inverter completely disconnected) needs to quickly know the car position in the shaft. More details in chapter 4.

1.2.3. The fact that the controller is aware of the electrical variables of the motor throughout the entire journey in real time, allows it to calculate the car load without using traditional load weighing devices. With this solution, we also evaluate motor and shaft efficiency. This is important in chapters 1.4 and 3.

1.2.4. In energy recovery solutions, it is important that the lift controller is aware of the batteries’ or capacitors’ loads and their temperatures.

In the same way, it is also important to know from the 3VF inverter the electrical power which the motor is requiring or is generating.

Taking into account these points, the lift controller can make decisions regarding the lift speed during or before starting a journey and therefore achieve a more efficient energy storage or reuse. More details in chapter 6.

This information is also important to manage a standby mode in which the stored energy is used to power the lift controller. It is also necessary to ensure minimum energy storage to ensure automatic rescue.

1.3 Direct approach system (DirectToFloor)

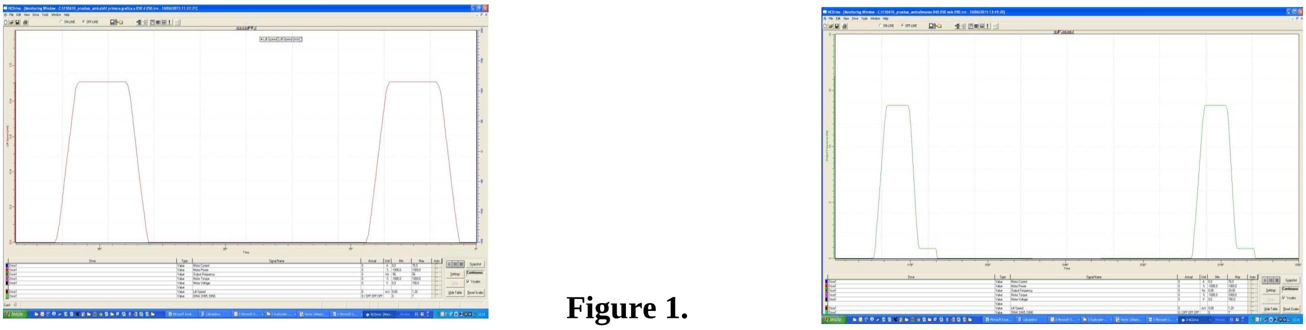


Figure 1.

Following on, the working mode which is already known and used in the lift industry is shown.

In figure 1, two graphs taken from the same lift are shown (speed vs time). On the left, the direct approach system is shown and, on the right, the traditional solution with approach speed can be seen.

This control system (DTF) has the following advantages well known among lift industry professionals.

Shorter journey times → improved passenger traffic pattern within the building.

1. Travel curve calculation depending on the distance to destination → improved comfort.
2. Reduction in time required for installation and maintenance.
3. A second encoder is not required to control the car position in the shaft.
4. The number of signals and sensors in reduced in the shaft when compared to traditional lifts.
5. Simple procedure for final adjustments.

1.4 Combined with DTF: Exceed the nominal speed of the gearless machine PMSM (VARIABLE SPEED)

There already exists, [9], a solution where the car speed can be modified depending on the differences in load between the car and counterweight. This can provide a reduction in the journey times.

This paper's solution is based on real time communication between the 3VF inverter and the controller at all times during the journey. .

An estimation of the car load and the motor and shaft efficiency is obtained during the journey.

In this way, in cases where the load difference between car and counterweight is less than the nominal value, the nominal speed of the motor can be exceeded. In this case, for example, with a traction lift designed for travelling at 2 m/s, by using this DTF solution, it is possible for the lift to easily exceed this speed and reach speeds of 2.5 m/s and without any increase in the electrical energy demand.

This solution allows travel times to be reduced by up to 20%, which improves the passenger traffic patterns in the building. This paper is not focused on this working mode, rather the energy savings it can offer.

In figure 2, the power demand for an MRL gearless lift, 1000 kg, 2 m/s, 50% balanced and with a 15.31m travel distance (IMEM test tower).

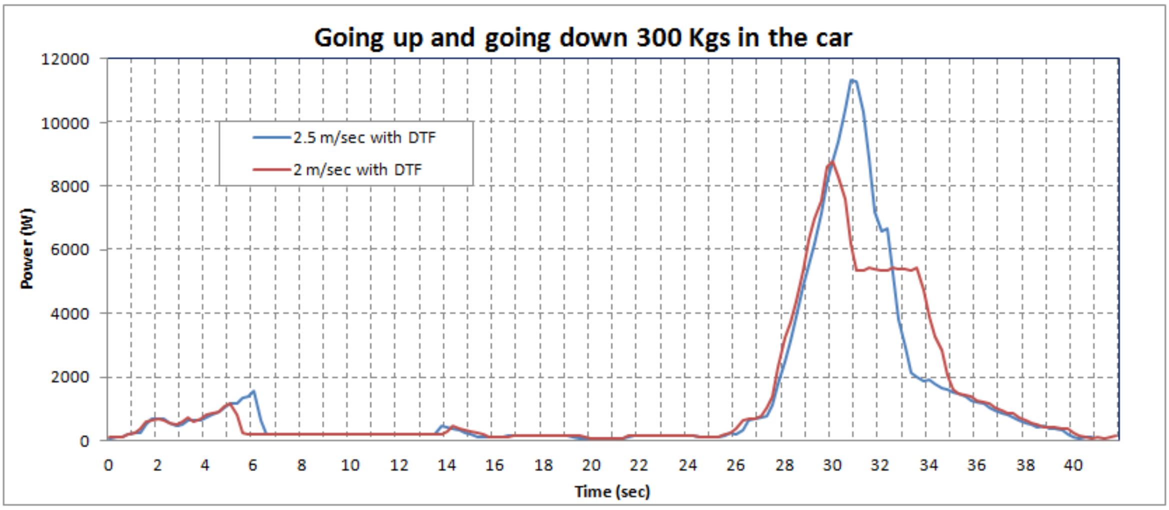


Figure 2.

2 ENERGY IMPLICATIONS OF THE DTF SOLUTION

Added to the previously identified DTF advantages, an energy saving is obtained by functioning as both a motor and a generator.

The energy saving is obtained, mainly, thanks to the elimination of the approach speed. Using DTF, the control reduces the energy losses in the motor during the journey, mainly produced because of the Joule effect in the stator.

Due to the temperature reached in the stator, an increase in the winding resistor impedance is produced, which will lead to a higher level of losses: Losses = 3 * Rf * If^2

The DTF mode, therefore, contributes to maintaining the motor temperature slightly lower.

In figure 3, the TOTAL power demand of an MRL gearless lift, 630 kg, 50% balance, 6.13m travel distance is shown. Analysis is below in table 1.

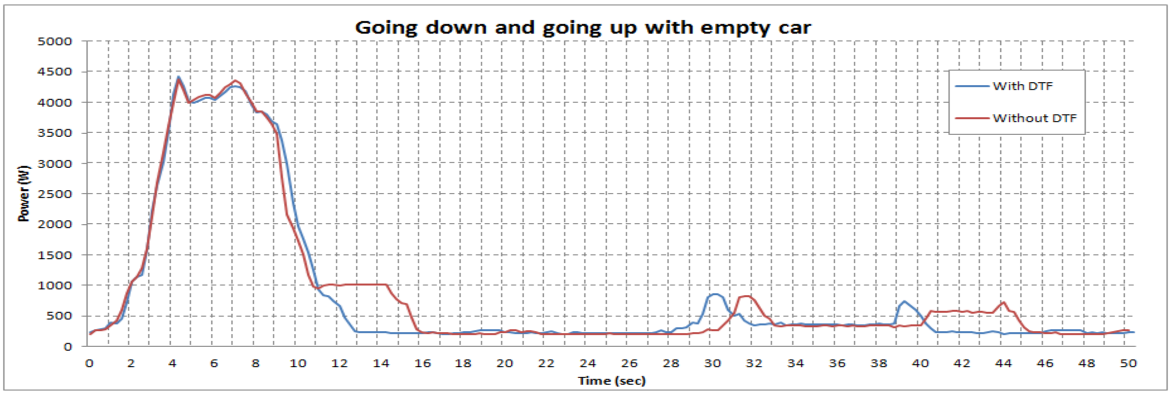


Figure 3.

	Energy	Energy	Time
Savings travelling upwards DTF	0.38 Wh	19.09%	
Savings travelling downwards DTF	0.74 Wh	7.85%	
Time savings		18.75%	3 secs (per journey)

Table 1.

In the following case, table 2, energy demands and savings are shown for an MRL gearless, 1000 kg, travelling at 1 m/s, travel distance 15.31m (IMEM test tower), empty car, 50% balanced.

Journeys: P1→ P2, P1→ P3, P1→P4. As shown, with shorter journeys, the savings are greater and more significant.

	DTF UPWh	DTF DOWN Wh	Total DTF Wh	CLASSIC UP Wh	CLASSIC DOWN Wh	Total CLASSIC Wh	Saving UP	Saving DOWN
3401 mm	1.27	8.31	9.57	2.42	9.45	11.87	**47.68%**	**12.10%**
7901 mm	1.54	16.45	17.99	2.70	17.59	20.28	**42.78%**	**6.50%**
10901 mm	1.73	21.87	23.60	2.88	23.02	25.90	**40.03%**	**4.99%**

Table 2.

The time saving also has implications in the savings made by the car lights (less time illuminated).

3 ENERGY IMPLICATIONS WHEN EXCEEDING THE NOMINAL SPEED OF THE MOTOR (VARIABLE SPEED)

The following data, figures 4 & 5, are obtained from an MRL gearless lift, 1000 kg, 2 m/s, 50% balanced, car load 100 kg. Travel distance: 15.31m (IMEM test tower).

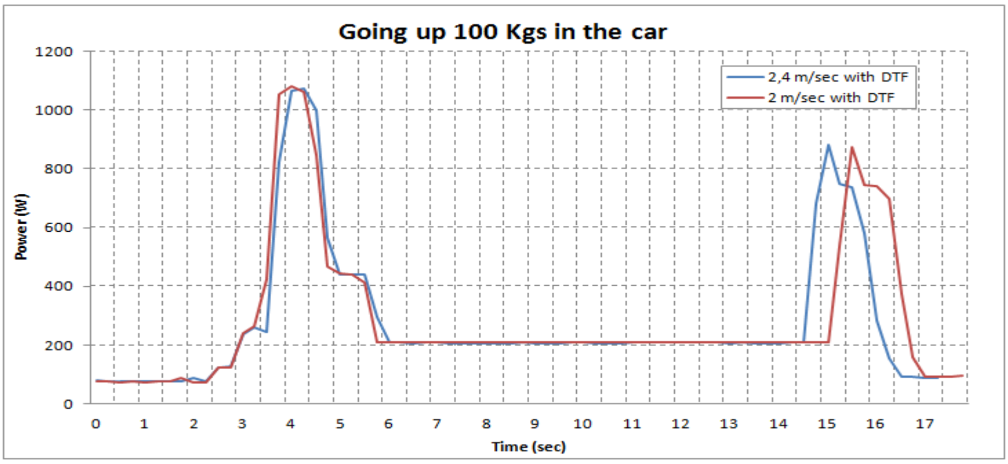


Figure 4.

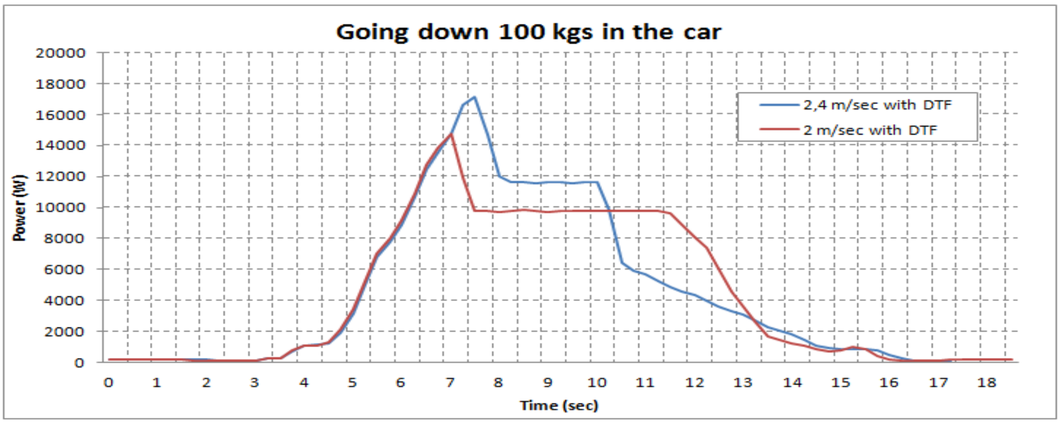


Figure 5.

In table 3, conclusions are detailed corresponding to the energy efficiency of the journeys shown in figures 4 & 5:

	2 m/sec	2.4 m/sec	4.47% Energy saving up. 0.48% Energy saving down.
Up	1.42Wh	1.36Wh	
Down	22.37Wh	22.26Wh	
Total	23.79 Wh	23.62Wh	

Table 3.

By making a calculation, using the data shown, it is possible to translate the results to **80m travel distance** (table 4):

	2 m/sec	2.4 m/sec	**11.85% Energy saving up.**
Up	3.29Wh	2.90Wh	

Down	110.28Wh	109.33 Wh	**0.86% Energy saving down.** **16.67% Approx. time saving.**
Total	113.57Wh	112.23 Wh	
Car lighting	6 LEDS	6 LEDS	

Table 4.

It is shown that the savings, both in time and in energy, increase in conjunction with the travel distance.

Values in table 4 are calculated as follows:

Reviewing the measurements carried out and shown in figures 4 and 5 and table 3:

Both in journeys travelling up and down, 3 stages exist (acceleration, constant speed and deceleration).

In order to simulate an 80-metre journey, it is taken for granted that the acceleration and deceleration phases are the same as those shown previously. The only difference would be the time spent travelling at constant speed.

Using the energy data obtained with the FLUKE 435 II analyser for the 15.31 metre journey, we obtain the Wh demanded for every 2.4 metres (for 2.4 m/s) and every 2 metres (for 2 m/s). The readings are taken each 10 millisecs.

For an 80-metre shaft and table 3 and figures 4 and 5:

Travelling upwards at speed of 2.4 m/s:

$$Wh_{travelling\ upwards\ 2.4\ m/s\ \ shaft\ 80\ mtrs} = Wh_{travelling\ upwards\ 2.4\ m/s\ \ shaft\ 15.31\ mtrs} + (80-15.31) * \frac{Wh\ upwards\ every\ 2.4\ mtrs\ constant\ speed}{2{,}4\ mtrs}$$

Travelling downwards at speed of 2,4 m/s:

$$Wh_{travelling\ downwards\ 2{,}4\ m/s\ shaft\ 80\ mtrs} = Wh_{travelling\ downwards\ 2{,}4\ m/s\ shaft\ 15.31\ mtrs} + (80-15.31) * \frac{Wh\ downwards\ every\ 2.4\ mtrs\ constant\ speed}{2{,}4\ mtrs}$$

Travelling upwards at speed of 2 m/s:

$$Wh_{travelling\ upwards\ \ 2m/s\ shaft\ 80\ mtrs} = Wh_{travelling\ upwards\ \ 2m/s\ shaft\ 15{,}31\ mtrs} + (80-15.31) * \frac{Wh\ upwards\ every\ 2\ mtrs\ constant\ speed}{2\ mtrs}$$

Travelling downwards at speed of 2 m/s:

$$Wh_{travelling\ downwards\ \ 2\ m/s\ shaft80\ mtrs} = Wh_{travelling\ downwards\ \ 2\ m/s\ shaft\ 15.31\ mtrs} + (80-15.31) * \frac{Wh\ downwards\ every\ 2\ mtrs\ constant\ speed}{2\ mtrs}$$

4 STANDBY MODE

This working mode is very important due to the fact that the lift spends the majority of its life in this mode.

Currently, lift devices such as displays and frequency inverters have standby functions available to be controlled by the controller.

There are cases in which the not very fast start-up time of these devices and the autotest processes need to be carried out before reaching READY state and/or the need to maintain information in their memory, obliging them to maintain a low level of energy consumption.

Thanks to real time communications information can be shared between devices.

In this way, by having only the controller working in standby mode, and it having all the information from the lift available, it is able to shut down the rest of the electronic devices, further reducing the energy demands. In this paper we focus on the shutdown of the 3VF inverter and the displays although further devices exist which can be completely disconnected.

In the case of the 3VF inverter, in order to shut it down completely, it is necessary to confirm in advance that the temperature of the IGBTs is correct. Otherwise, their lifetime can be dramatically reduced.

When the inverter is completely shut down, its energy demand is zero.

This working mode allows the traditional standby energy demands to be eliminated. For example, an estimation of 2 current inverter models (2 very well-known European manufacturers).

Inverter A In = 32 Amps: 27 W when idle, 13 W on standby → 0 W

Inverter B In = 14 Amps: 19.7 W when idle, 8.7 W on standby → 0 W

In order to switch the inverter back on (exit standby mode), it is important to estimate the temperature of the DC bus pre-charge circuit. If this is not done, the inverter can be damaged or have its lifetime reduced.

When switching the inverter back on, with DTF lifts without second encoders (a second, more expensive element), it is necessary to inform the inverter about the car position in the shaft. In this way, the time required to reach READY mode is reduced and provides a quick response to the passenger request.

In the case of the displays, when switched back on, it is fundamental to know, via field bus, when ready mode is reached in order to send them the information which must be shown quickly. This solution allows them to be switched off completely rather than keeping them on standby mode. Measurements from the displays of 2 very well-known European manufacturers:

Display 7’’: 8.64 W when idle, 3.12 W on standby → 0 W

Display 3’’: 13.48 W when idle, standby mode not available → 0 W

5 REGENERATIVE SOLUTION + ENERGY RECOVERY SYSTEM

To be able to reuse the energy generated by the motor, there are mainly two alternatives; return the energy to the grid or store the energy. Returning the energy to the grid is an interesting, well-used option, and regenerative drives have been available for some time. Again the problem is the uncorrelated events of generation and use. Energy returned to the grid may be used by another system that happens to be consuming at the same time (for example a neighbour lift) or can be accounted for in countries where net metering is available. In general, it is almost impossible to determine with precision how much of that energy is actually being saved by the lift owner.

This paper uses a recently developed market-available technology of storage [2, 3] with positive results. Figure 6 shows the schematic diagram of the system that has been added to the lift

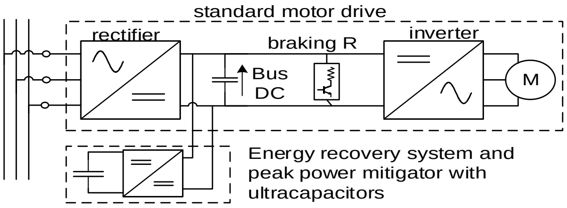


Figure 6 Electronic diagram of connection of storage system to DC bus of VVVF drive.

As can be seen, the system requires only two wires connected to the VVVF drive so it is very simple to install. Although it is not required, further information may be at the disposal of the controller (see section 6 below). The system has two parts that may be integrated in a single module: a DC/DC converter that transforms the energy into something that can be easily accumulated and the actual accumulator. This one, depending on the application, can be a set of batteries or ultracapacitors.

In this particular case, a study has been carried out with two different versions of the energy storage system. The two versions are different in terms of power handling capability and in available energy storage modules. Table 5 shows the two versions that have been evaluated. Lift: MRL Gearless 1000 kgs, 50% balanced, travel distance: 15,3 m.

Table 5. Two different versions of energy recovery systems

	Converter power	Energy stored
Version 1	3.5kW	100kJ (flexible)
Version 2	6.3kW	60kJ

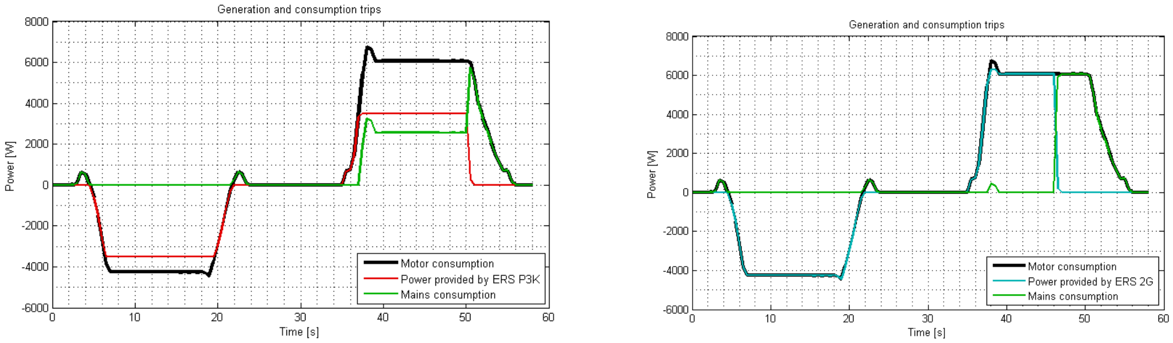


Figure 7 Power vs. time of the lift without saving system (black) and a) using version 1 and b) with version 2. Consumption from mains and energy provided by energy storage and conversion system [15,3m trip with no load in the car]

Figure 7 shows two trips of maximum generation and maximum consumption, motor power vs. time. The actual curves of a measured version 1 system effect in the lift are presented in red. The power function of the effect of a simulated version 2 system in the same case is presented in blue First of all, it is important to mention that the lift, has a remarkably high efficiency, measured at 83%. Secondly, the power handling capability of the version 1 system, limited to 3.5kW, does not allow the storage of all the available energy in the generation journey, with part of that going to the braking resistor. Nevertheless, version 2, with 6.3kW of power conversion, allows the storage of more energy. The effects can be seen in the last part of the consumption journey, with version 2 supercapacitors being depleted later than with version 1, resulting in higher savings. Table 6 shows the numerical results obtained for the particular case of version 2.

Table 6. Energy calculations for test lift for maximum ratings

Max. power consumed	6059 W
Max. generated power	4246 W
Efficiency of installation	83.71%
Energy consumed in one trip	95.66 kJ = 26.57 Wh
Energy generated in one trip	62.63 kJ = 17.40 Wh
Savings with version 1	50.05%
Savings with version 2	59.30%

Traction energy saved is estimated as 59.30% with the second version of the system. A VVVF inverter efficiency of 96% has been considered, as well as 98% unidirectional efficiency of the DC/DC converter (which implies 95% bidirectional efficiency). With version 1 of the system, savings are lower, due to the above mentioned fact.

ISO 25745-2 [1] and state-of-the-art literature [5, 6, 7] relate actual daily energy calculations to a set of parameters that have an impact in this study. In this paper we have taken these into consideration and we have measured the impact of the version 1 system in the energy savings for the different classes of operation by means of considering the number of trips, load and distance. At the time of the tests, version 2 of the technology was not available, which is why version 1 was used. 365 days per year are considered for the particular lift mentioned before table 5. The results are as follows:

Usage category 1: 98.91 kWh/year (without recovery system), 39.17 kWh/year (with recovery system).
Usage category 2: 247.03 kWh/year (without recovery system), 97.92 kWh/year (with recovery system).
Usage category 3: 592.88 kWh/year (without recovery system), 227.69 kWh/year (with recovery system).
Usage category 4: 1442.84 kWh/year (without recovery system), 571.89 kWh/year (with recovery system).
Usage category 5: 1967.42kWh/year (without recovery system), 779.82 kWh/year (with recovery system).
Usage category 6: 1520.15kWh/year (without recovery system), 524.89 kWh/year (with recovery system).

As a summary, we can conclude that the inclusion of a recovery system reduces the lift's energy consumption in a variable percentage (dependent on version and category of use) that in general is above 35%. These savings levels are the starting point for section 7.

6 COMBINING DTF + VARIABLE SPEED + ENERGY RECOVERY AND STORAGE SYSTEM

Several studies have been carried out which focus on energy recovery and storage systems such as [8]. Different behaviours and uses of the energy have been studied.

From our point of view, there are two factors to take into account when storing and reusing electrical energy.

a.-The capacity for managing the power of the DC/DC converter. In certain circumstances, the lift can generate or demand more energy than the DC/DC converter can deal with.

b.- Storage capacity in the ultracapacitors module.

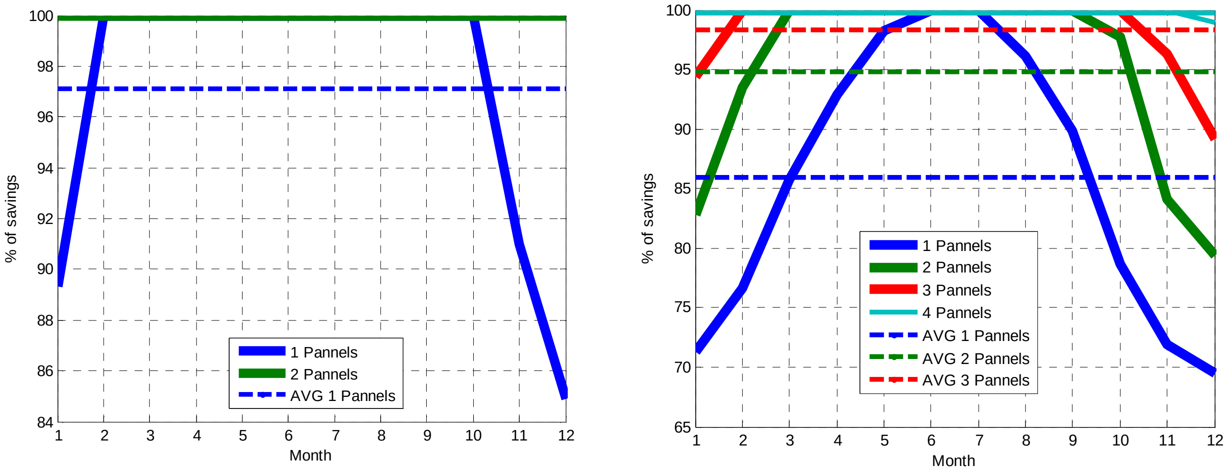
Communication using a field bus between the controller and the DC/DC converter allows, amongst other things not applicable in this paper, monitoring in real time the load state of the ultracapacitors and the flow of energy between the DC bus and the storage module.

The lift controller, using DTF and VARIABLE SPEED, can reduce or increase the travel speed (if the building's passenger traffic allows), and increase the efficiency of the generation/reuse of energy in these cases.

7 SOLAR PANELS

To be able to use alternative energy sources, especially solar panels, the generated energy needs to be transformed to a usable form of energy for the lift. In general, solar or wind energy require some storage to buffer the generation and the consumption. Again, thanks to the transformation and storage capabilities provided by the tested energy storage and recovery system, we have been able to easily add solar panels as an energy source without any need for additional electronics.

For this particular case, the energy storage capability is a relatively small one. Typically, this would be for one or two trips in maximum consumption mode. The intention was not to make a completely solar powered and self-sustainable lift. To do so, batteries are needed and there are alternatives [2, 3]. The intention was to further reduce the consumption. The test lift that has been used is the same as in section 5, with the addition of solar panels. The solar panels that have been considered are: Power: 295W, Area: 1,95 m2, Voc: 45V, Vmpp: 37V, Cells: 72



a) b)

Figure 8 Estimated savings (in %) with Version 2 and solar panels by month: a) category 2 lift, b) category 5 lift.

Figure 8 shows the expected savings depending on the number of panels installed and the month of year in Santander (north of Spain). The efficiency of the solar panels provided by the manufacturer has been taken into account and radiation has been considered to be the average statistical data for the city. It already considers that the savings obtained with an energy storage system (as mentioned in section 5, table 6). In addition, for the particular case of a category 5 lift and depending on the month of year, average savings can be increased to more than 85% with just the addition of one solar panel, without the need for any additional electronics**.** These estimations vary, of course, with latitude of installation and class of operation but they highlight very promising results for this option in terms of improving the energy efficiency.

The whole system (energy recovery system), including solar panels has a possible range of ROIs that is highly dependent on location, cost of energy and features of the lift installation. Typical cost of solar panel is slightly less than 1€ per Watt.

8 CONCLUSIONS

The use of the DTF system as standard in any traction lift provides considerable electrical energy savings, especially with traffic between floors (1-3, 3-5, etc.).

The DTF system has to be used as Standard without additional costs to the lift. The intelligence of the lift controller reduces to a minimum the adjustments (the number of components is not increased, it is reduced); and these are simplified thanks to software.

The combination of DTF with VARIABLE SPEED (over-speeding the motor) significantly reduces the journey time and provides improvements in energy efficiency.

The passenger traffic requirements in the building could be managed better without necessarily the need for more lifts or higher motor powers. This is due to the journey time reduction thanks to DTF and over-speeding the motor above its nominal speed. In accordance with [10], and for 2 lifts (duplex) example: MRL traction lift, 13 person, 13 floor, floor-to-floor distance: 4 metres, door opening time: 5 secs, building population: 100 person, car load percentage: 65%.

Estimated data at 2 m/s and at 2.4 m/s.

	Case A. 2 m/sec	Case B. 2.4 m/sec
Handling capacity 5 minutes (%)	47.72	51.7
Waiting time (secs)	34.52	31.87

Using this data, the only guaranteed conclusion which can be reached is that the increase in speed helps to reduce the two variables shown and that DTF + VARIABLE SPEED brings the data from cases A & B closer together.

Regrettably, it is not possible to define the level of improvement and how close the data from case A can be brought to case B.

It has been possible to improve standby modes thanks to real time communication and the sharing of information between devices.

The evolution of the current regeneration systems to energy recovery systems with storage capabilities has led to the intelligent management of electrical energy when storing or reusing energy.

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BIOGRAPHICAL DETAILS

Mr. Vicente Pacheco de las Cuevas, Ms.Sc. in Physics (Specialising in Electronics) (2000), University of Cantabria (Spain). Starting work in IMEM Lifts in the year 2000,nowadays, he manages the Electrical, Electronic and Automation area of the R&D Dept.

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Dr. EstanisOyarbideUsabiaga, Ph.D. in Industrial Engineering (1998) by Institut National Polytechnique Grenoble, France and degree in Industrial Engineering by the University of Mondragón, Spain. From 1998 to 2002 he was lecturer at the University of Mondragón, Spain and since 2002 assistant lecturer at the Engineering School at the University of Zaragoza.Researcher in more than 20 projects in energy conversion, most of them with big companies (Iberdrola, Ingeteam, Renault, CAF, Fagor, Acciona Wind Power, Orona, Schneider Electric, etc).

Mr. Luis Ángel Jiménez Alonso, Ms. Sc. in Electronics Engineering, University of Zaragoza (2013). He has worked in the telecommunications industry, developing power converters for radio and TV. After that, he joined a research project at the University of Zaragoza for the automotive industry. Currently Engineer at Epic Power.