Comparing the Energy Consumption of Elevators with Different Drive Technologies

Stephan Rohr, Ingo Pletschen

ThyssenKrupp Elevator Innovation GmbH, Bernhaeuser Str. 45, 73765 Neuhausen, Germany, Stephan.Rohr@thyssenkrupp.com

Keywords: energy efficiency, lift, drive technology, machine, Ward-Leonard, Modernization.

Abstract. In the last decades the drive and machine technology has made a big step forward also in regards of energy efficiency. This also improves the energy efficiency of lifts, significantly, which strive towards the ultimate and unattainable goal as a perpetual motion machine. While lifting loads and persons, electrical energy is converted into potential/kinetic energy and reconverted later. Measurements which compare different drive technologies are usually conducted at different lifts, where also the mechanical system varies. An increase or decrease in energy consumption may be caused by the mechanical system and not by the drive. This paper introduces measurements of different drive technologies used in the last decades and compares lifts, where also the mechanical part is the same. Furthermore, these lifts are simulated with state of the art drive technologies. The energy saving potential is identified and the different drive technologies are being compared.

1 INTRODUCTION

New installations of lifts are usually equipped with PSM[1] machines, today. This is due to the high energy efficiency, low noise in comparison to geared machines, and shaft efficiency in the MRL[2] market. In the modernization market there is still a high amount of lift installations which are equipped with voltage controlled inverters and machines with gear boxes or Ward-Leonard drives.

A lot of these lifts will be modernized within the next years. The main challenge is to find a cost optimized and sustainable solution which fits best into the market segment. In particular, if only a part of the lift e.g. the drive system is modernized while the mechanical system persists this could be a sustainable solution. However, there are many possibilities to modernize a lift, starting with the replacement of single components to a full replacement. This leads to many different configurations and thus it is economically impossible to install and measure all this variants. Therefore in [1] a simulation environment has been introduced and validated at a real lift, but detailed information about the parameters is required. Usually this information is not on hand for old drive technologies and thus this paper compares different drive setups at a lift where energy consumption has been measured before and after the modernization. These measurements are extended by simulations to evaluate also further variants.

A closer look at the modernization market of rope lifts, especially with a look at the replacement of the drive system, leads to the question: Which components of the drive system should be replaced to find an economical and energy efficient solution?

In case of a full replacement of the total lift (comparable to a new installation) either a PSM with non-regenerative or a PSM with regenerative drive should be used. It is proposed to use a regenerative drive system even in the low rise market segment [3].

---

[1] PSM: Permanent Magnet Synchronous Machine
[2] MRL: machine roomless lift

In case of a partial modernization for low-rise lifts also the combination of state-of-the-art geared machine with regenerative inverter shows interesting economical and high energy saving benefits, which has been shown in [2].

This paper focus on mid-rise lifts, where often Ward-Leonard drives has been used in the past. In particular, the energy savings are proven by comparable measurements. In the following chapters existing drive technologies are briefly described and measurements and simulations are performed to evaluate the energy savings of different configurations.

2 OVERVIEW OF DIFFERENT DRIVE SYSTEMS

The considerations in this paper are based on rope lifts, hydraulic lifts have not been considered. In rope lifts the cabin and counterweight is usually balanced with around 40-50% of the rated payload, which is today's standard.

Figure 1 shows the simulated energy consumption, to get a general idea about the differences between a low-rise (left) and high-rise (right) elevator. On the left axis the active power and on the right axis the speed is given over the time. Additionally, the regenerative part of the energy is marked by the green area. The high inertia of the high-rise elevator leads to a high acceleration and deceleration peak power in comparison to the nominal travel and therefore the overall system inertia has a big influence on the energy consumption and calculation.

For the simulation results in chapter 4 it is necessary to use an accurate model to obtain appropriate results, which has been discussed in [1]. Especially the use of characteristic maps for the efficiency during acceleration and deceleration is important while the use of formulas with constant efficiencies leads to high deviations [1].

For the low-rise elevator in figure 1 the down travel with empty cabin consumes around 18.4 Wh, The travel in upward direction recovers -5.7 Wh into the grid. Thus around 31% of the energy is recovered, which also considers the non-recoverable part of idle consumption of controller and light. For the high-rise elevator even 62 % of the energy is regenerated, which results from a higher efficiency of the machine, as well as a low idle consumption in comparison of the energy consumed by the drive.

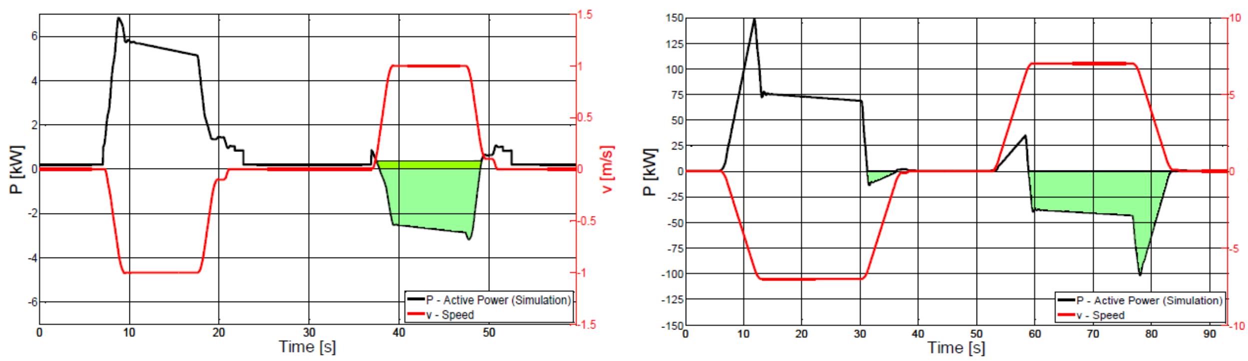

Figure 1 Comparison of Energy Consumption of a Low- and High-Rise Elevator

A closer look in the modernization market leads to different types of drive systems which have been used over the years. The most common systems are:

- Two speed machine
- Ward-Leonard drive (Motor generator)

- Phase-fired controllers (ACVV[3] drives)
- DC machine with thyristor controller
- Geared machine with VVVF[4] controller based on IGBT[5]
- Gearless machine with VVVF controller based on IGBT (mostly in combination with PSM)

Usually, an inverter with regenerative drive unit has the highest power factor as the wave form of the regenerated current is controlled. Looking at the history, the Ward-Leonard drive has been installed until 1970. The major part of installations has been modernized so far mostly by static inverters where the DC machine has been kept in the installation (this was practice until 1980) [4]. Starting in 1990s the gearless drives with IGBT controller has been widely used and is the most common drive system, nowadays.

3 MEASUREMENTS

In this chapter a Ward-Leonard drive system is compared with a gearless induction machine driven by either a regenerative or non-regenerative inverter. Already, in 1995 first energy measurements have been conducted at a modernization site in Stuttgart, Germany. A Ward-Leonard drive has been replaced by a gearless induction machine including an IGBT inverter. The shaft equipment and car have been kept in the installation, while the controller and drive system were changed. The main parameters of the lift configuration are shown in table 1.

Table 1 lift configuration

Type of drive system:	Ward-Leonard	Gearless machine "DA330" with inverter "API60R"
Lift data	Q = 1,200 kg Vn = 2.5 m/s; Roping = 2:1 Total travel height = 52 m with 13 stops Car and counterweight with roller guides	
Type of motor	DC motor (HGF 2682-4)	Induction motor (DAF330 M002)
Traction sheave	600 mm	440 mm

The configuration of the drive system before and after the modernization is shown in Figure 2. The left figure shows the Ward-Leonard drive which was originally used, where the lift's motor was a DC machine. Due to the three stages of energy conversion the overall efficiency is very low. In the right figure the modernized drive system is shown, where the inverter is controlled by power electronics (PE) driving an induction motor.

---

3 ACVV: Alternate Current Variable Voltage
4 VVVF: Variable Voltage Variable Frequency
5 IGBT: Insulated Gate Bipolar Transistor

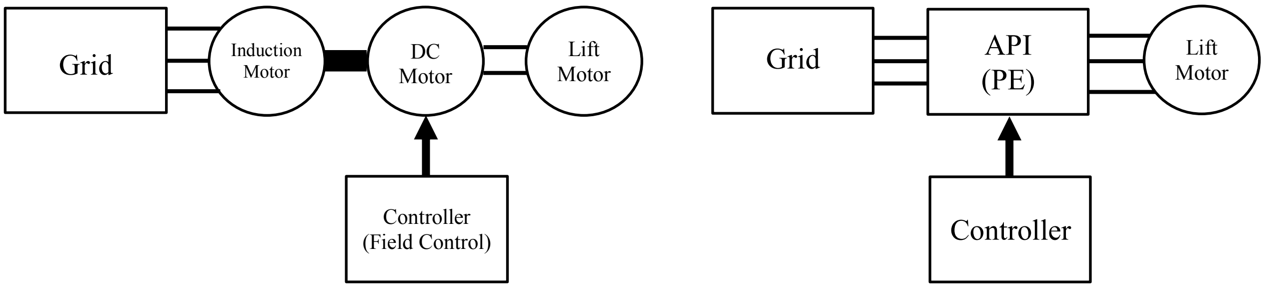

Figure 2 Ward-Leonard Drive in Comparison to a Gearless Drive with IGBT Technology

A travel of the Ward-Leonard drive with no payload is shown in Figure 3. It is a travel between the floors 10 and 13 in down and up direction. The red curve shows the speed (right axis). The black curve shows the active power. Even if the lift is stopped the Ward-Leonard drive system "wastes" – in this configuration – about 10 kW. For acceleration a peak power of almost 70 kW is needed. In addition, the reactive power is higher than 20 kVar which leads to a worse power factor. From the figure it is also visible, that the Ward-Leonard drive is able to recover energy which is shown in green. However, due to the low efficiency only little energy is recovered.

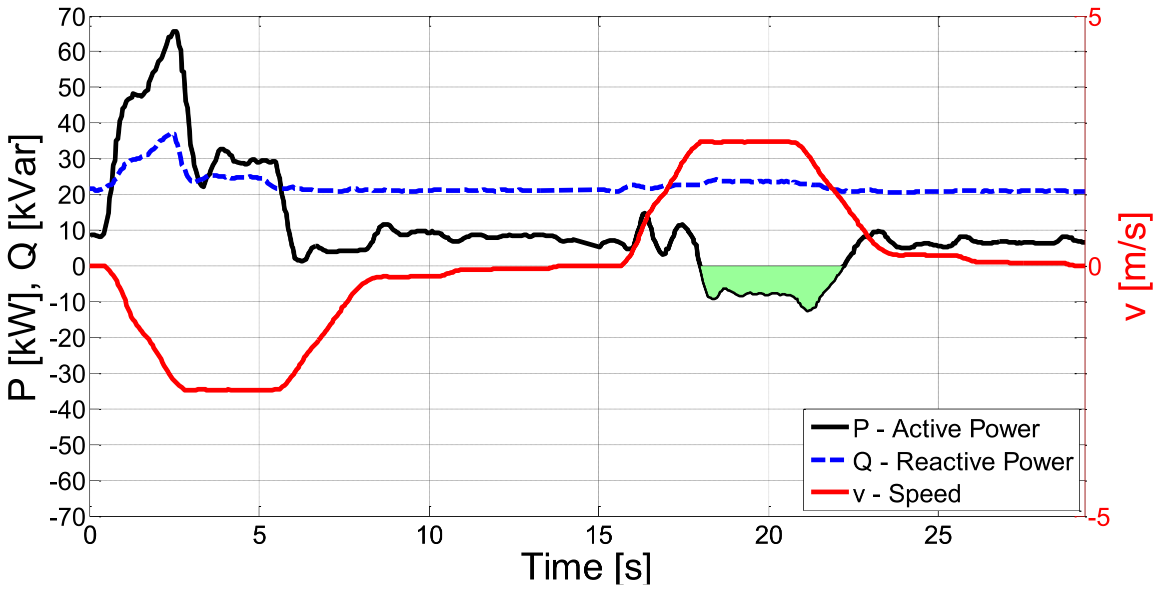

Figure 3 DC Machine with Ward-Leonard Drive System

Now, the results are compared with the induction motor driven by the IGBT inverter "API60" which is shown in Figure 4. The active peak power for accelerating the lift is reduced to 40 kW that is about 43 % of reduction. The up travel with no load recovers no energy, as the first measurements have been made with a non-regenerative drive system.

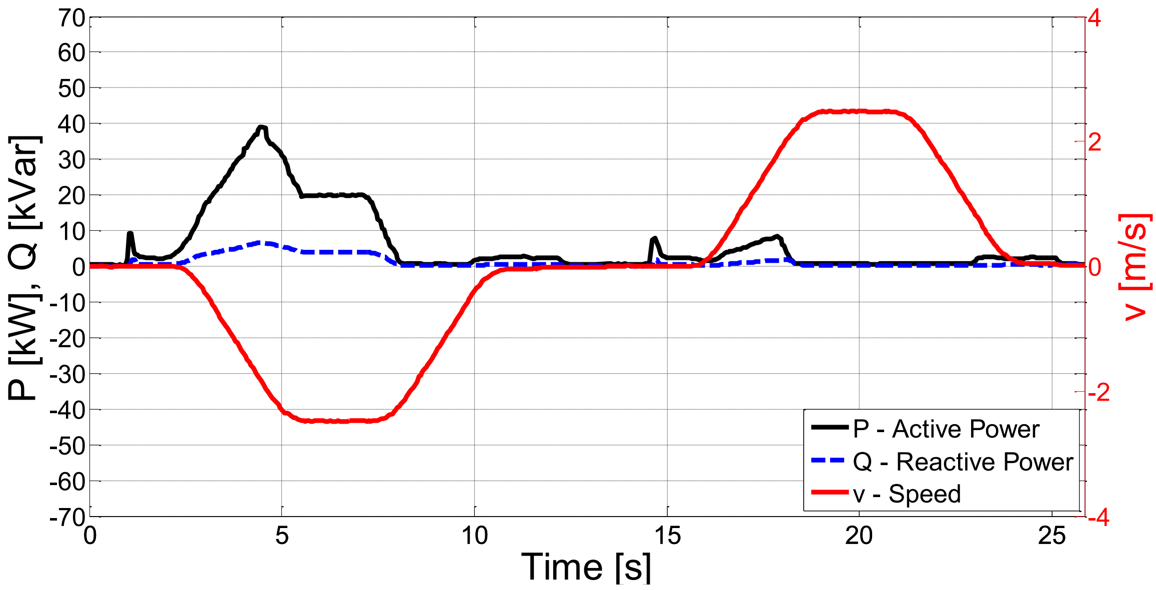

Figure 4 Compact Gearless with non-regenerative API Drive

Figure 5 shows the same drive configuration as in Figure 4, but the inverter "API60-R" with energy regeneration has been used. The regenerated part is shown in green.

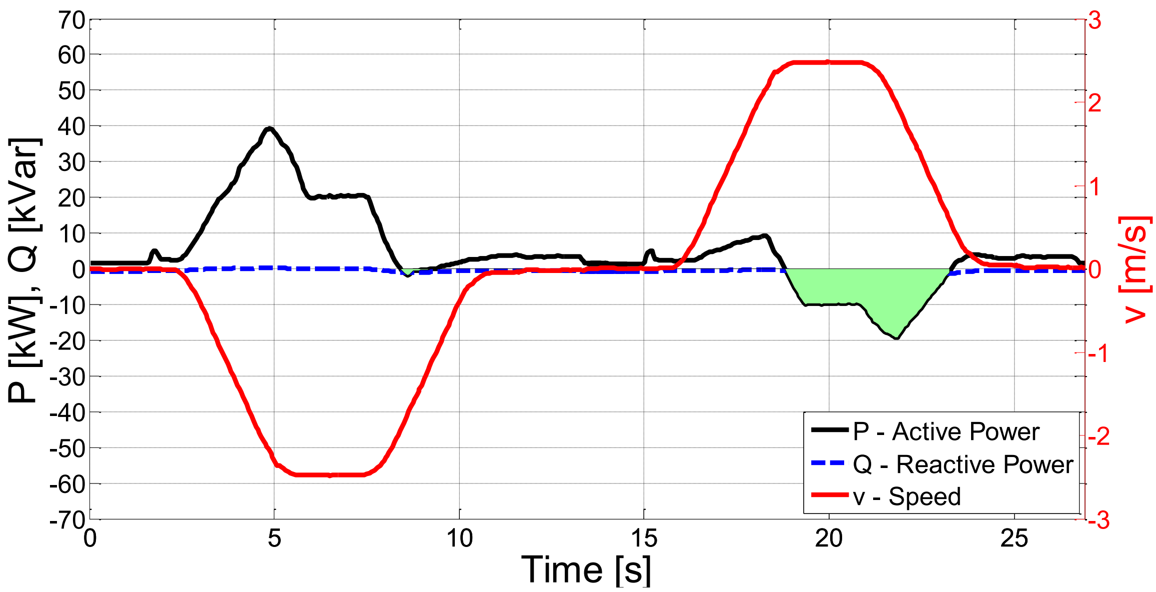

Figure 5 Compact Gearless with API regenerative Drive

Looking at the total energy consumption a comparison has been performed based on the travel cycle about 104 m stopping at the following landings: 13-2-1-2-13. The specific demand of the Ward-Leonard drive system has been measured with 2.04 Wh/m. For this cycle, even the induction machine without energy recovery consumes 36 % less. Furthermore, if compared with the regenerative drive the energy consumption is even lower and 53% less. This difference resulting mainly as for the Ward-Leonard drive system the energy is converted three times between mechanical motion and electrical energy. Also, the high masses of the machine rotors contribute to the higher energy consumption. Additionally, the strongly reduced peak power and increased power factor of the inverter drive which becomes more and more important for stabilizing today's grid.

Table 2 shows a summary overview of the energy consumption per year and connecting power. The energy consumption per year of the Ward-Leonard drive has been measured over 1.5 months and was then extrapolated for the whole year. The lift performed around 1170 runs per day while having 4.8 hours running time. Furthermore the annual demand of the induction machine with inverter is estimated based on the above mentioned driving cycle.

Table 2 Energy demand of different drive systems

	Ward-Leonard	Induction machine Non-regenerative	Induction machine Regenerative
Mains connection [kW]	33.0	19.2	19.2
Energy per year [kWh]	18,535	9,996	8,442

4 SIMULATIONS

The measurements of the chapter above are now compared with a simulation of the same configuration but application of state-of-the-art technology. Therefore a PSM, a VVVF inverter with regenerative drive unit and an up-to-date mechanical design is used. The lift's parameters are given in table 3.

Table 3 Parameter of the simulated lift

m_K [kg]	1200	Mass of empty cabin
m_G [kg]	2386	Mass of counterweight
m_{ZL} [kg]	1677	Maximum Payload
H [m]	52	Travel Height
J_m [kg m²]	3,6	Inertia of traction sheave
r_T [m]	0,22	Radius of traction sheave
AufH	2:1	Roping
ρ_{Seil} [kg/m]	2,8	Specific mass of all ropes

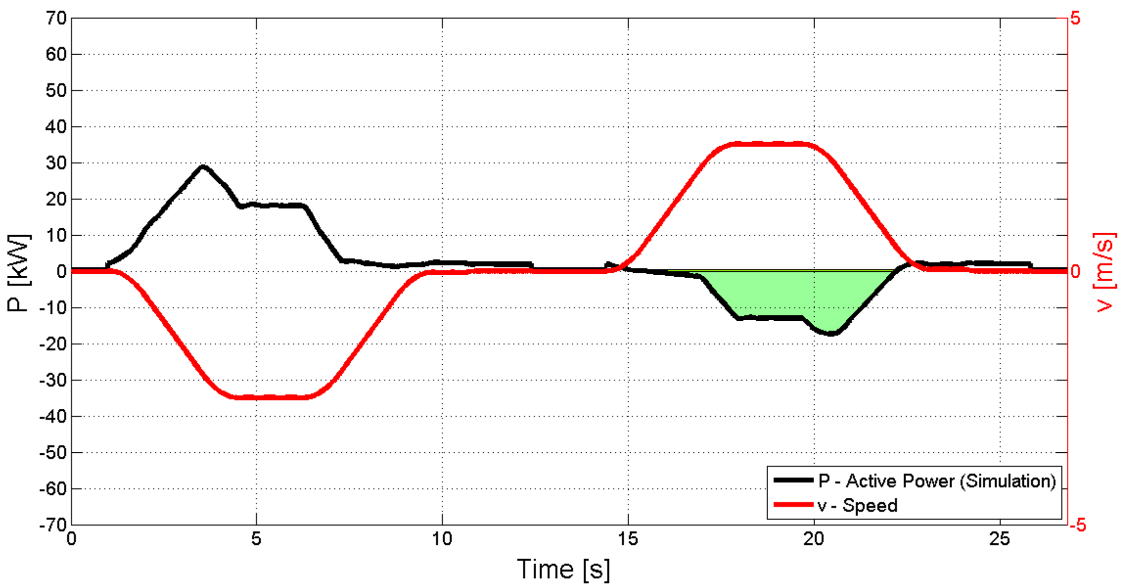

Figure 6 PSM machine with regenerative drive

Figure 6 displays the results of the simulation. Comparing the energy consumption of the lift containing the PSM drive the energy savings in regards to the Ward-Leonard drive are again significantly decreased to around 80 % during the travel cycle between floor 10 and 13. In addition, the peak power is further reduced by 10 kW. Looking at the whole travel cycle, around 47 % can be recovered during the travel in up direction.

Especially the higher efficiency of the PSM leads to smaller losses, resulting in reduced power consumption during the downward travel with empty car, as well as to higher energy recovery during the upward travel. Thus, a high energy efficiency of the drive doubles the energy benefits. Also the inverter has a higher efficiency due to transistors with fewer losses, resulting from advances in the semiconductor industry since 1995.

5 CONCLUSION

With introduction of the VDI 4707 in 2009 and the ISO 25745 which will be introduced soon the overall energy consumption of a lift becomes more and more important for new installations.

Even in the modernization market these figures can be used to make a modernization of a lift more attractive to the customer due to the high potential of energy savings.

The overall energy consumption of a Ward-Leonard drive in comparison to state-of-the-art technology results in up to 80 % energy savings if replaced by a PSM drive system. Even in old fashioned IGBT technology with induction machines further significant energy savings potential exists and a modernization become attractive to the customer.

REFERENCES

[1] Pletschen I., Rohr S. and Kennel R. *Simulation und Analyse des Energiebedarfs von Aufzugssystemen*. Proceedings of ETG Kongress (2011).

[2] Pletschen I., Rohr S. and Kennel R. *Simulation, Validation and Analysis of the Energy consumption of elevators*. ELEVCON (2014).

[3] Rohr S. and Pletschen I. *Energy recovery with lifts*. Elevatori. Issue 2 (2011).

[4] Unholzer, M. *Energiekennwerte von Personenaufzügen. Forschungsprojekt am KIT im Rahmen der Forschungsinitiative Zukunft Bau.* Heilbronner Aufzugstage (2014).

BIOGRAPHICAL DETAILS

Dr.-Ing. Stephan Rohr studied electrical engineering at the University of Stuttgart, Germany, and received the Dr.-Ing. degree from the University of Ulm, Germany, in 2006. Currently, he is Head of the Product Design Center CENE at ThyssenKrupp Elevator Innovation GmbH.

Dipl.-Ing. Ingo Pletschen studied electrical engineering at the University Karlsruhe, Germany. He is with ThyssenKrupp Elevator since 2009 and is working towards the Dr.-Ing. degree in cooperation with the Technical University Munich, Germany. Currently, he is responsible for the department “Innovation Process” of the Product Design Center CENE of ThyssenKrupp Elevator Innovation GmbH.