# A Supercapacitor-Based Energy Storage System for Elevators with Soft Commutated Interface

Prof. A. Rufer, Dr. P. Barrade

Laboratoire d'électronique industrielle, LEI,

EPFL, Ecole Polytechnique Fédérale de Lausanne

CH 1015 Lausanne, Switzerland

**Abstract**

In recent years, power variations and energy criteria has been the main motivation for developing regenerative drive converters for elevators [1]. A more performant solution for power-smoothing can be easily found by using a supercapacitor based storage device, connected to the intermediary circuit of a Variable Speed Drive system.

In this paper, power and energy considerations are made for the design of the storage tank and regarding the maximum power demand from the feeding network. For the power-conversion circuit, which is necessary to compensate the voltage variations of the supercapacitors by descharging and charging, a high efficiency converter topology is proposed which allows the bidirectionnal energy flow under soft-commutation conditions, and offers also a good flexibility for the optimal sizing of the supercapacitor voltage level.

The typical behaviour of the special converter is given, together with an analyse of the advantages related to the specific application.

## 1 Introduction

Supercapacitors represent one of the newest inovations in the field of electrical energy storage, and will find their place in many applications where energy storage can help to the smoothing of strong and short time power solicitations of a distribution network. In comparison with classical capacitors, this new components allow a much more higher energy density, together with a high power density. Fig. 1. gives an illustration of the amount of storable energy in comparison with classical electrochemical capacitors of similar size.

Even if the energy density is not comparable with that one of electro-chemical accumulators, the possible energy amount and storage time is compatible with many industrial requirements. In transportation systems, as a first example, the energy needed to relay two bus-stations can easily be transferred from a fixed supercapacitive storer to another one placed on the bus, during passenger transfer time, allowing so the use of electrical propulsion without trolleys [2]. Other complementary storage systems for better share of energy and instantaneous power amounts have also been described [3], as well as supercapacitor tanks as booster for fuel-cell powered passenger cars [4].

Classical electrolytic capacitor

100’000 µFarad/16V

E = 12.8 Joules

ECDL Supercapacitor

800 Farad/2.5V

E = 2500 Joules

## 1. Basic strategy for capacitive energy storage

For capacitive energy storage, two different loading strategies can be used. A first one is the interconnection between a constant voltage source and the capacitor via a series resistor. By that strategy the horizontal red curve in Fig 2 illustrates the poor efficiency of η=0.5, as the main property of the exponential charging, independently from the time constant.

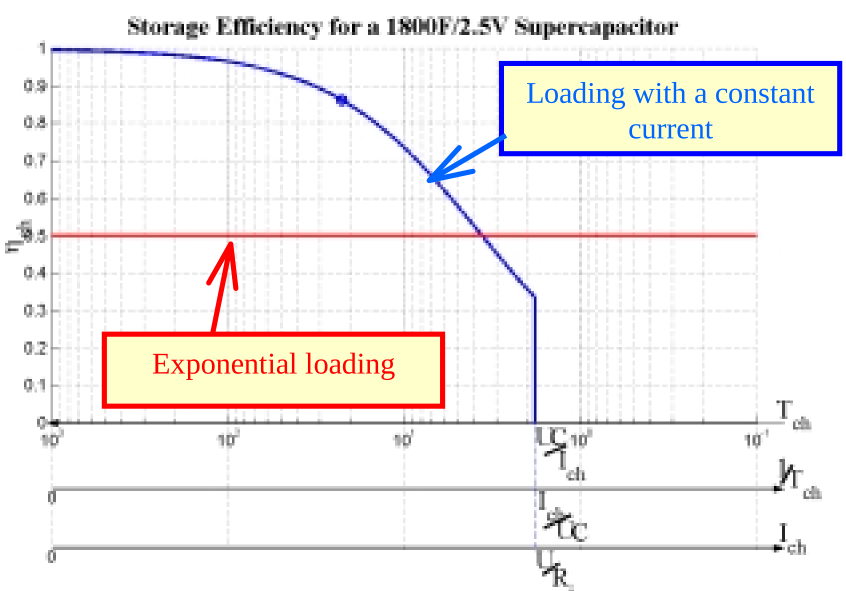



Fig. 2. Efficiency by exponential and by constant current charging

Only a charging with constant current is able to reach acceptable efficiency, equal to 1 if the current is kept extremely low. The increase of the current causes a decrease of the charging time, but increases the losses inside the internal resistor (blue curve). Only power electronic solutions with control circuits can achieve this type of energy transfer between a constant voltage source and a capacitor. Elementary and multi-channel boosters are state of the art in this field, and have been intensively described [3].

## 2 The power requirements of elevators: a solution with energy storage

Elevators have typical load cycles characterised by a low energy balance between up and down movements, but they have a high power demand during acceleration in the up direction, an also a high power restitution in the down movement, especially by the deceleration [1]. When on one hand the strongly modulated power demand represents a problem of availability of the feeding network, on the other hand, the generally used breaking resistors in the frequency converter of the variable speed drive must be shown as the cause of a high amount of wasted energy.

More recently, economic considerations have lead to compare the price of the wasted energy over longer time with the money saved by the choice of a cheap non-regenerative input rectifier of the drive converter. The solution of using a regenerative rectifier circuit appears as evident, even if its price is higher than the price of the simpler circuit.

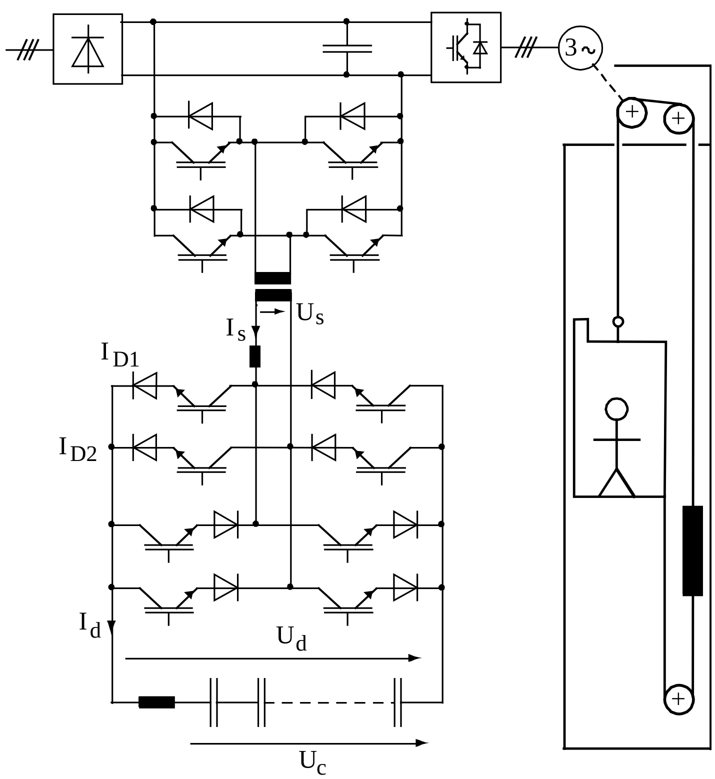
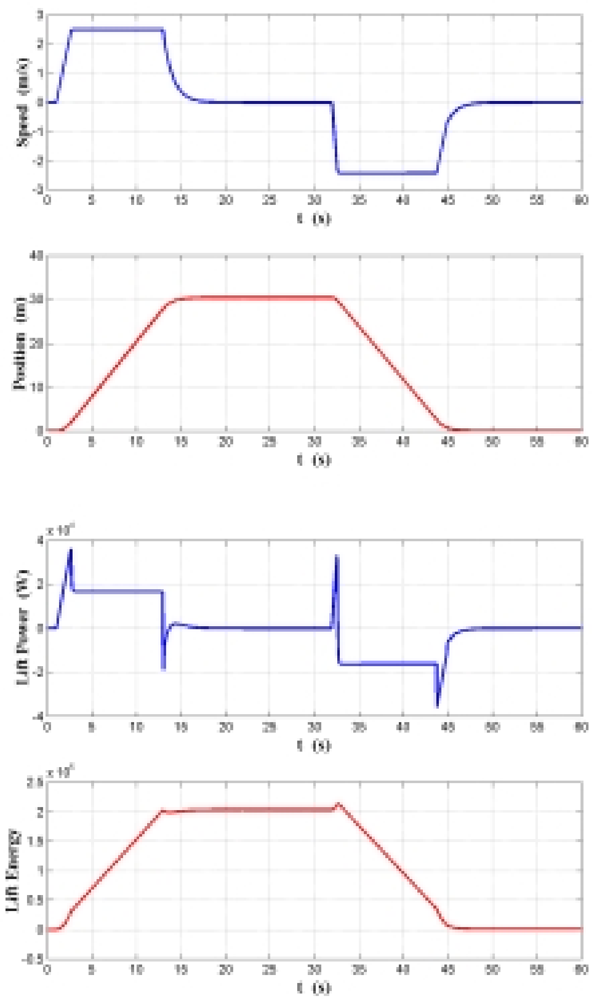



Fig. 3. General scheme of the elevator-drive with supercapacitor-storage

Such an amelioration in the energy balance does not solve the problem of the high power peaks appearing at the coupling point and also the induced voltage variations or flicker effect. To solve that particular problem and simultanously the difficulties of the tarification of the re-injected energy by the utility, a solution with energy storage is proposed. An overview-scheme of the drive-converter with storage interface is given in Fig. 3.

In that solution, the supercapacitor storage device can cover not only the energy needed by the elevator dynamics, but also the energy used by the vertical force during the travelling at constant speed in the case of unbalanced elevators. The typical power demand of an elevator for a movement up to the tenth floor and down to the same level is shown in the curves of Fig. 4. In the first and second parts of the figure, the elevator speed and position are represented, while the corresponding power demand and energy consumed are shown in the third and fourth parts.




Elevator speed

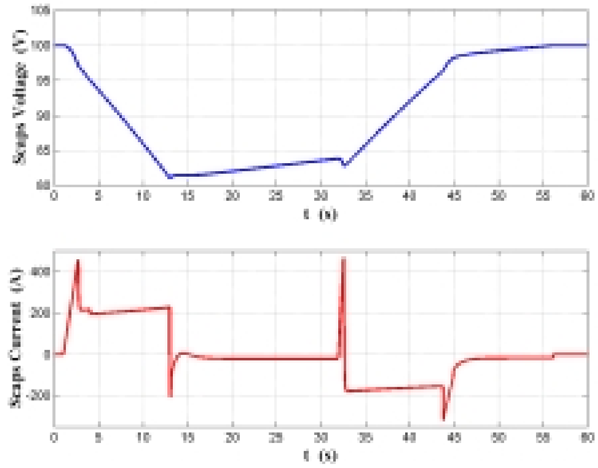
Elevator position

Instantaneous power

Consumed energy

Fig. 4: Ten floor up-and down run

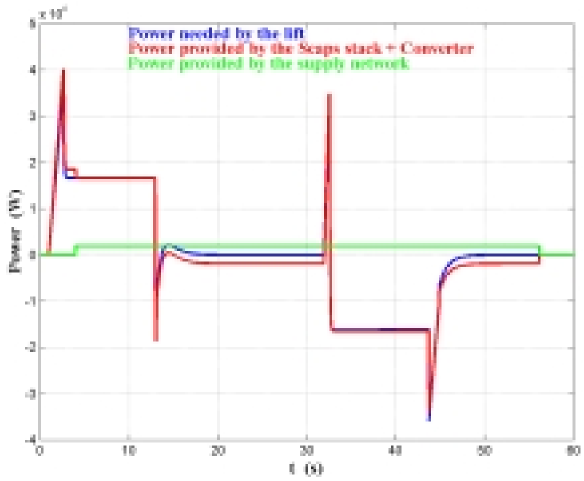
The different curves of fig. 4 have been calculated by simulation for a real elevator with a car weight of 720 kg, balanced with a counter weight of 1440 kg. The car was loaded with 1400 kg. The energy amount needed for the 10 floor up-run is equal to 220 kJ, or 62 Wh. The maximum power demand is equal to approximately 33 kW.




Voltage level of the supercapacitive tank

Current in the supercapacitors

Fig. 5.a): Voltage and current of supercapacitors




Power needed by the elevator, and provided by the supply network

Fig. 5.b): Power demand

The figure 5 shows the typical behavior of a supercapacitive tank associated to the previously described elevator requirements. Based on the result of the needed energy amount, it must be verified that a supercapacitor tank is able to deliver the maximum needed instantaneous power, reached at the end of the acceleration phase of the up-run (Fig. 4). A non-optimal energy design criteria has been considered, because the power ability is critical. Considering a maximum value of the current in each 1800 Farad supercapacitors equal to 150A, the design of the tank leads to an oversized maximum energy capacity of 675 kJ. That value corresponds to a global capacity of 135 Farad under a full load voltage of 100 Volt. The array of the tank is then a 40 series connection of 3 paralleled elements, as a total of 120 elements. A single 10-floor up-run causes consequently a voltage decrease down to 82 Volts, extracting so 67% of the energy capacity. One interesting phenomena is visible on the diagram of Fig 5b, which concerns the supply network. As soon as the supercapacitor voltage has come under a presetted limit, the primary charging unit is beginning to take a constant power from the distribution system. This power level which is the only solicitation of the elevator system of the primary grid is equal to 2.5 kW. In a complete up-and-down cycle (10 floors), were the 14 sec. up- and 14 sec. down runs are separated with 8 sec. stops, the tank keeps fully charged.. Even if the efficiency of the store/unstore cycle has not been calculated with a high accuracy, the new power demand with storage is a considerable progress compared to the value of 33 kW of the conventionnal solution.

### 3. Parallel and series connections

The realization of supercapacitive tanks of large capacity uses a large number of individual cells, that can with advantages be operated at a high voltage level with series connection.

However, the series connection of supercapacitors of not strictly equal C-values can lead to an unequal share of the cell voltages, mainly as a result of the integration of the common (series) current. Active voltage sharing devices have been proposed, using power electronic switches with low on-state losses [5], and able to get good equalised voltage values of each individual cell. However, even when such a solution is unavoidable for reaching a full load status and to protect the supercapacitors from aging, the added price for the symmetrizing devices can lead to problematic costs for this technology.

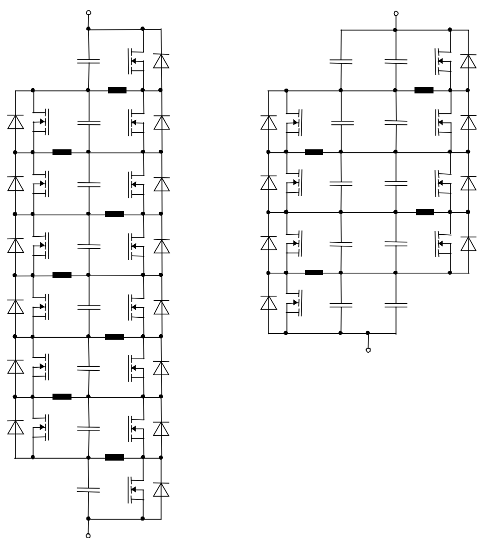


Fig. 6. Organising the series/parallel connections of the cells for better voltage sharing

Another possibility in order to limit the costs of the symmetrizing devices is to choose a parallel connection at each voltage level, getting naturally a better equalising of the capacitor values, and reducing so the current capability of the symmetrizing apparatus, and dividing so the total number of needed components

Figure 6 shows the proposed scheme for an active symmetrized series connection of supercaps, and also the advantages of the reduced number of additional devices in the connection with paralleled capacitors. An optimal arrangement must be chosen by designing such a storage tank, bringing advantages in the symmetrizing costs, and simultaneously getting a sufficiently high efficiency of the needed converter for the voltage adaptation.

## 4. Adapting the voltage-level with transformers

The voltage-level of a storage tank is mainly determined by the design of the concerned application. Like by classical Voltage Source Inverters, several applications in the traction field need voltage levels in the upper hundred-volts range, eventually in the lower kilovolt range for very high power systems.

A good solution for getting the voltage of the supercapacitive tank adapted to the level of the application is to use an electromagnetical transformer. Younger developments with increased performance of magnetic materials allow the operation of the transformers in the range of ten kilohertz. One possible solution for the use of an MF transformer with a static conversion topology based on resonance is given on fig. 7, where the high- voltage side of the transformer is interfaced with the the DC link of the frequency converter via a four-quadrant H-bridge operating in resonant mode. The low-voltage side has also the same converter scheme, with in addition a buck converter, needed because of the typical variation of the supercap voltage by loading and unloading.

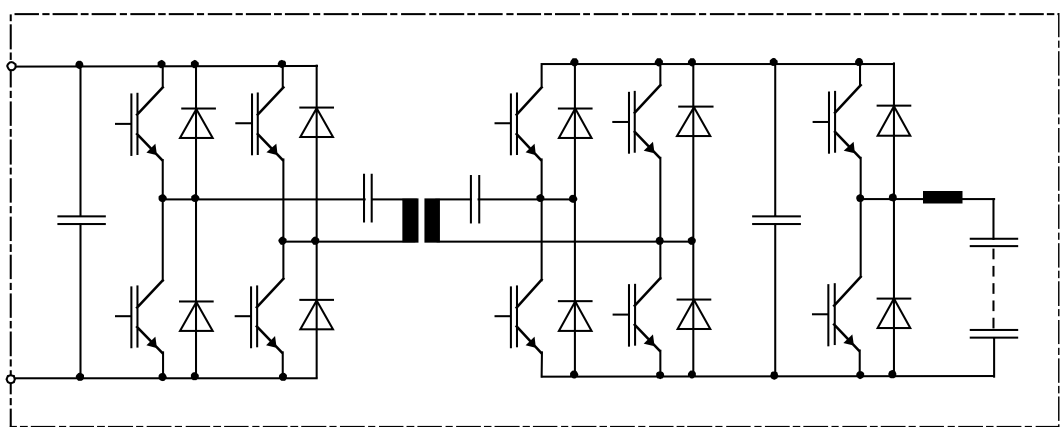


Fig. 7. Voltage adaption with an intermediary AC-link with MF-transformer, topology with resonant mode

### 4.1. Increasing the efficiency with ZVT/ZCS technology

In the scheme proposed in figure 7, the number of cascaded converters between the DC-link of the frequency converter and the storage tank is equal to 3. Especially the conduction loses but also the commutation loses of the Buck converter will in that case limit the total converter efficiency.

For an alternative solution with higher efficiency, ZVT/ZCS technologies have been studied [6], and are of high interest in this case of application.

I II III IV

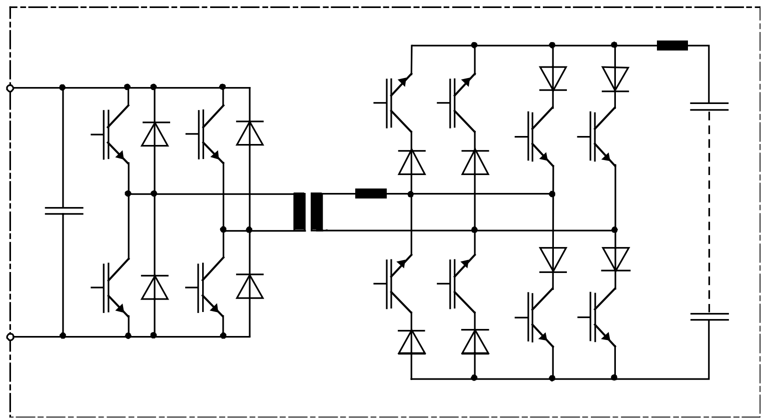


Fig. 8. MF-AC-link with ZVT/ZCS converters

### 4.2 Modern soft-commutated converters with AC link at medium frequency

In the scheme of Fig. 8, the alternative solution for the voltage adaptor is shown. Two static converters are used, the first between the DC link of the drive, (I), and the primary side of the MF transformer (II). The second converter (III) is placed between the secondary winding of the transformer and the storage circuit composed by a series connection of a smoothing inductor and the supercapacitors (IV).

## 5 Operating principle of the high efficient, soft-commutated power-converter

The first converter-bridge of Fig. 8 is a VSI operating in the fundamental-frequency switching-mode, that means that the generated AC current changes its polarity after each change of the polarity of the generated AC voltage. This way of operation is well known for its very low commutation losses. It is also called ZVT-converter, or also VSI with Dual-Thyristors [6].

At the secondary side of the transformer, a naturally commutated current converter (or ZCS current-converter) is represented, in a current-reversible topology, using 2 anti-paralleled TCR bridges. The operation frequency of these bridges, which is the frequency of the MF transformer is designed in the lower kilohertz range. It demands particularly low storage time of the power semiconductors, and is not realisable with conventional thyristors [7], [8]. For the realisation of the ultra-fast thyristor function, IGBT's are used with a series connected diode. At the output of that AC-DC conversion circuit, the rectified and angle-controlled voltage waveform cannot be applied directly to the supercapacitor tank, but needs a decoupling and smoothing reactor which is also represented on Fig.8.

From the point of view of the commutation losses, the stresses at the constant DC level are not appearing because of the ZVT phenomena of the IGBT inverter operating in the fundamental switching mode. So high-volume components can be used without any difficulties of commutation of diodes. At the secondary side, a higher amount of conduction losses is due to the series connection of the diodes and of the transistors.

The absence of commutation losses (ZCS) keeps the total efficiency at an acceptable level.

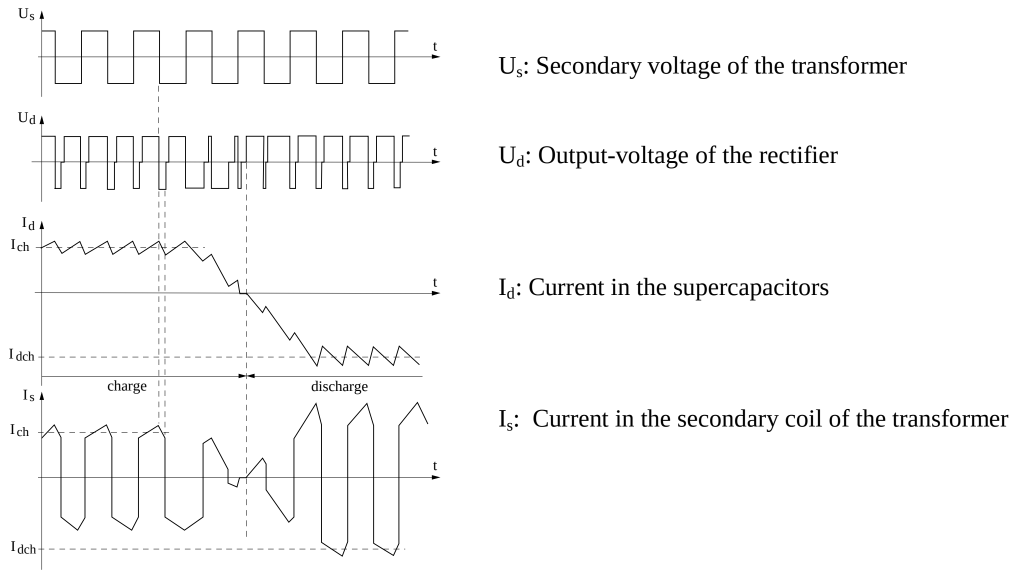



Fig. 9. Operating principle of the soft-commutated converter

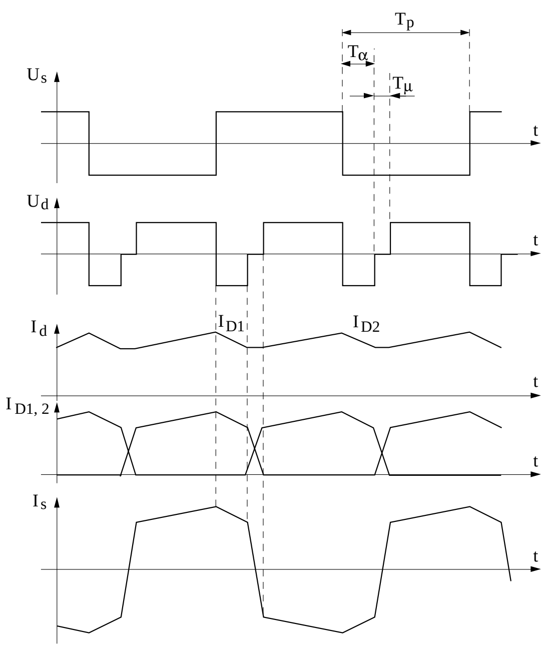



Fig 10 Commutation phenomena in the MF-current converter

The typical waveforms of the conversion circuit quantities are represented in Fig. 9, for both the loading with positive, and unloading with negative current of the energy storage tank. The voltage at the secondary-side of the transformer is shown, together with the rectified instantaneous DC-voltage. The third curve on Fig. 9 shows the supercapacitor current, in the charging and in the discharging mode. The TCR bridges are operating in the corresponding rectifier- and inverter-mode [6], [7].

In Fig. 10, the detailed waveforms are represented, showing the commutation effect of the TCR bridges. Together with the pulsating period $T_p$, the time corresponding to the firing angle $T_\alpha$ and the time corresponding to the commutation angle $T_\mu$ are indicated. Even with a relatively high frequency of the AC link, the commutation voltage drop can be kept low, according to a small value of the commutation reactor. A typical behaviour of the voltage drop of this type of rectifier has been modelled [8], taking in account of a possible capacitive commutation-aid across the IGBT's of the ZVT inverter. An additional reactor can also be necessary on order to assume the perfect transition of the voltage of the switches of the ZVT bridge by low output current, respectively in the ZVT commutating devices.

## 4 Conclusions

In this paper, power and energy considerations have been made for the design of a storage tank used for the levelling of the load of an elevator drive. A high amelioration can be reached regarding the power demand of such a system from the primary distribution network.

For the power conversion circuit necessary to compensate the voltage variations of the supercapacitors by charging and descharging, a high efficient converter topology has been proposed, which allows the bidirectional energy-flow under soft-commutation conditions. That solution offers also a good flexibility for the optimal sizing of the supercapacitor voltage level, and reduces the number of components in the load equalising circuitry of the series-connected supercapacitors. Power Electronic circuits with current-controlled mode are unavoidable for reaching an acceptable efficiency in the charging and descharging cycle of supercapacitive tanks.

## 5 References


[1] B. Ashok, H. Nguyen, E. W. Gaudet, A comparative evaluation of line regenerative and non-regenerative vector controlled drives for AC Gearless Elevators, IEEE IAS 2000, Rome, October 2000.

[2] P. Barrade, A. Rufer, Power smoothing and high power fast energy exchange between storage systems, International Conference on Quality and Security of Electrical Supply, The Oxford Belfry, Thame, UK, ERA Technology LTD Surrey KT22 7SA, UK

[3] A. Rufer, H. Ravokatrasolofo, Static converter for complementary energy storage with batteries and supercapacitors, PCIM 99: International Conference on Power Conversion and Intelligent Motion, Nürnberg (D).

[4] H. Stemmler, O. Garcia, A Simple 6-way DC-DC Converter for Power Flow Control in an Electrical Vehicle with Fuel Cells and Supercapacitors, EVS 16 Conference, Beijing 1999.

[5] P. Barrade, S. Pittet, A. Rufer, Energy storage system using a series connection of supercapacitors, with an active device for equalizing the voltages, IPEC 2000 : International Power Electronics Conference, Tokyo (J).

[6] Y. Cheron, Soft commutation, Chapman and Hall, 1992

[7] P. Coulibaly, Convertisseurs réversibles à commutation douce, Association onduleur de tension/commutateur de courant, Thèse 1998, ENSEEIHT, Toulouse, France

[8] C. Chabert, A. Rufer, Optimisation des convertisseurs de puissance embarqués : Adaptation des cellules à lien alternatif MF et commutation douce, 8e Colloque « Electronique de Puissance du Futur », Nov. 2000, Lille France