POWER ELECTRONICS FOR HIGH DYNAMIC DRIVES

Prof.-Dr.-Ing. J. M. Pacas
Institute for Power Electronics and Electrical Drives
University of Siegen
Hölderlinstr. 3,57068 Siegen
pacas@lea.e-technik.uni-siegen.de

Dr.-Ing. Armin John
Micromatik GmbH
Frankfurter St. 27, D-57074 Siegen
Armin.John@Micromatik.com

ABSTRACTS-In modern mechatronics new concepts of machines and processes are found by using the collected knowledge of all disciplines and by offering functional solutions. Most of the problems in the field of mechatronics demand technical innovations on the field of actuators, sensors and control methods. It demands also high dynamic drives with power electronics, able to cope with the new requirements. The paper presents some trends and industrial experiences with power components for high dynamic drives.

1. INTRODUCTION

The principal aims of the mechatronics are the enhancements of the machines and processes regarding:

- the costs,
- the throughput in the production,
- the flexibility of the machine or process,
- the easiness of use and
- the quality of the process

One way for the achievement of this target is the substitution of mechanical components by intelligent ones. Key components for this effect are high dynamic digitally controlled intelligent drives which are equipped with intelligent power electronic actuators. Thus it is evident that mechatronics has an enormous impact in the development of power electronics of high dynamic drives as it will be seen in the following. The paper considers the three main power electronic components used in the drives: the inverter, the DC-link and the power supply for the electronics. As it will be exposed the requirements for high demanding applications are different as in the case of conventional drives. In some applications it is possible to recur to servo-drives "off the shelf" and modify them so that they fulfil the special demands of the application. In some other cases it can be advisable for the machine builder to undertake the development of the power electronics in order to get an optimised system.

2. POWER COMPONENTS FOR HIGH DYNAMIC DRIVES

Inverters

Inverters for high dynamic drives in principle do not differ from conventional ones. Nevertheless the new mechatronics concepts as well as the required electrical characteristics influence their development in several ways: toward new intelligent switches suitable for high switching frequencies and toward a higher degree of integration of switches [1], cooling, heat sinks and internal low inductance wiring. But as a matter of fact the main effort is the fulfilment of the special features in high dynamic drives.

For applications in the lower torque range like robots and servos for the general automation the volumes are high enough so that the development of special solutions can be cost-effective [2]. Such solutions integrate the control electronics and the power switches obtaining all advantages of compactness, wiring, EMC etc. Thus the degree of automation in assembling and testing can be considerably enhanced. The integration of heat sink and switches is however not common.

Very important in inverters for high dynamic applications is also the mechanical design. Since they are often used in multi-axis applications the so called "book-shelf-design" has a lot of advantages over the "shoe-box-design" common in conventional drives. It makes the connection of several drives to a common DC-link easier and minimises the width of the cabinet. Harsh and high polluted environment conditions as they are found in many fabrication processes have also led to special designs of heat sinks.

Especially relevant for high dynamic drives is the EMC not only in terms of compliance with the international standards but particularly regarding the EMC compatibility inside the drive. On the one hand due to the dynamic requirements high values of di/dt are expected and in the other hand the measurement of the rotor position must be carried out with a very high resolution. So special care in wiring (signal- and power- cables are installed close together) and shielding for cables, wires and cabinets are compulsory.

Some features concerning the operation of the drives in machines and the pertinent regulations also play a role : Safety requirements, safe operation during set-up, noise etc. The fulfilment of these demands presupposes their consideration in the design of the inverter. For instance some regulations require galvanically isolation of the gating units for the state "controller inhibit" in the set-up operation. This design is unusual in conventional drives and must be taken into account. Other regulations concern the fast shut-down of the DC-link in case of failure etc.

All these aspects are considered in the design of modern servo-inverters in the lower power range. Many suppliers offer this kind of servos - usually as packages consisting of an inverter and a drive- with manifold built-in functions. They can be used as single axis and multi-axis drives commonly operated as torque controlled or speed controlled amplifiers with conventional interfaces. In the power range above approximately 20 kW the volumes are low and the cost for the development high, for this reason only few suppliers for high dynamic drives can be found. Furthermore due to different reasons the drives are not always suitable for a given application and some machine builders and end users develop the inverters by themselves as it will be explained later in the paper.

New converter topologies and controls are of advantage for high performance drives. The often in the literature proposed resonant topologies have not found any considerable acceptance in the industry. For resonant topologies special modulation and control schemes are required. Since the main efforts of the last years were focused on the development of PWM-inverters this technology will predominate in the near future.

The direct torque control (DTC) [3] which is comparable to the DSR [4] control scheme developed by Depenbrock is also an alternative of deep significance. It is used in all new series of drives of ABB and leads to excellent dynamic performance especially in the field weakening range. It is therefore also utilised for high dynamic drives in high demanding applications. Nevertheless it is a proprietary solution of ABB.

<u>DC-link</u>

The most common configuration for the feeding of the DC-link in standard industrial drives is a diode-bridge on the net-side. This is surely not the most suitable one for high dynamic drives. Thus two important issues must be considered:

- The regenerative or storage capability of the DC-link and
- The net harmonics

Especially when multi-axis systems are considered, the DC-link wins a special importance. Often the braking energy from one axis can be used for the acceleration of another axis. This can be accomplished by a common DC-link for the involved axis. Other more sophisticated modes of operation demand a dedicated control of the DC-voltage and imply in some cases intelligent power supplies able to communicate with the superimposed control.

A typical acceleration profile required for the high dynamic applications considered here is depicted in Fig 1. The diagrams show simplified speed profiles of a direct drive rotary shear. The acceleration time from 0 to 100% speed is below 100ms and depending on the profile ab to 10 cycles per second are possible.

The fact that acceleration and deceleration phases are following periodically to each other can be exploited for the optimisation of the DC-link. So the energy fed back during the braking phase can be transiently stored in the DC-link and used for the following acceleration phase. So the dimensioning of the DC-link capacitor must be carried out according to this requirement. The management of the energy in the DC-link becomes easier by using a boost converter for its feeding. Compared to simple rectifier this will not only reduce low frequency harmonics and optimise the power factor but also – using a patented smart control scheme – only the losses are recharged to the capacitor bank at constant sinusoidal current from the 3-phase mains. This is surely one option for the realisation of DC-link configurations. In other cases it is advisable to use a full voltage inverter on the net-side. By using this solution sinusoidal currents on the mains as well as controlled DC-link-voltage are possible. Although a full inverter in the net-side is preferred in the last time for modern drives, it does not fulfil a very important requirement namely the brake capability in case of a black-out. Therefore a combined topology consisting of an inverter in the mains and a braking chopper for the emergency braking can be necessary.

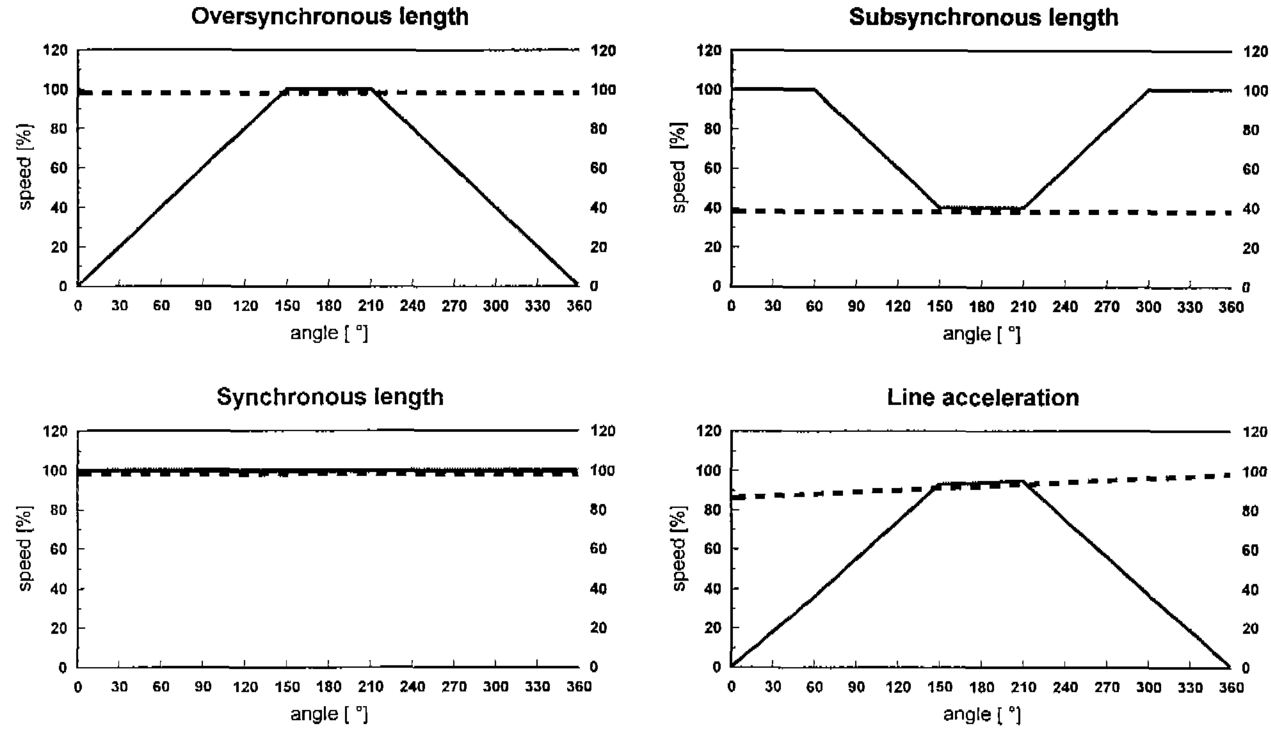

Fig. 1 Speed profiles of a typical rotary shear

Power supply

It is also well known that the units for the power supply of the electronics are very important in the context of the mechatronics and high dynamic drives. In standard drives the common solution is a power supply fed out of the DC-link. The power supply for the electronics functions above a minimal voltage and is kept alive as long as the DC-voltage does not fall below a certain value. This scheme is not appropriated for high demanding applications. The reasons are:

- The drives must function before the DC-link capacitor is charged. This requirement results from the necessity of a communication between the numerical control and the drive before the main switch is turned on. Because set-up procedures must be carried out prior to the operation, i.e. the drives must be configured and parameters must be set, the drive controller and the sensors must be in operation during this time.
- After a mains failure the drives must function at least for a short time. This feature allows the realization of appropriate shutdown strategies. Basically the shutdown procedure should avoid damages on material and tools. In continuos processes (paper and metal) a rupture of the strip is fatal because of the subsequent downtime and the cumbersome feed-in procedure. So the strategy for a blackout is to brake all the

drives in coordinate way. The second requirement is often the storage of all the data logged in the drive: parameters and state variables at the time of the shut-down in order to ease the diagnosis an the trouble shooting. For these effects the control electronics must be supplied without interruptions.

The requirements for an continuously power supply of the control electronics before and after the switch-on of the system can only be accomplished by means of a redundant power supply (Fig. 2) or a system with a battery back up. In some cases the numerical control has anyway a UPS that can be used for the drives provided that they are compatible e.g. 24 Volt.

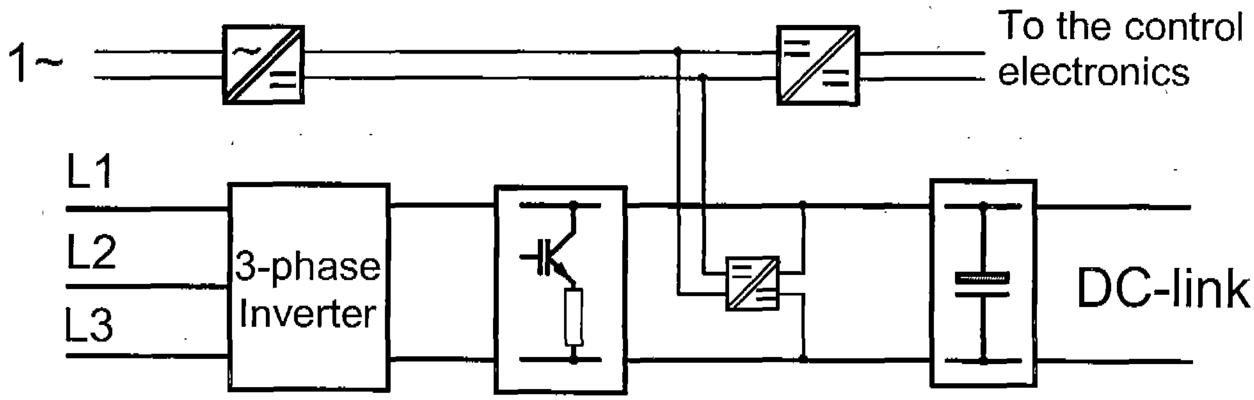

Fig.2 Redundant power supply for the electronics

3.TAILORED POWER ELECTRONICS FOR HIGH DYNAMIC DRIVES

The choice of appropriated drives has an important impact in the design of every machine and must be considered very carefully. The choice for high demanding applications with high dynamic drives becomes difficult, because the core of the specification for most conventional inverters target the high volume markets. Special applications are supposed to be attained by *slight modifications* of the basis hardware or basis software. The choice becomes more complicated in multi-axis systems with tight synchronisation among the axis because not only the features explained above but also the control system and the communication between the control and the axis are of a specific art.

In some segments of the market the volumes are high enough so that the development of dedicated series of drives for the specific applications makes sense. In these cases *complete* solutions for machine-tools, printing machines, packaging machines, lifts etc. complying with all above mentioned special features are available. The machine builder purchases thus a system and not a component. Special requirements for a concrete application can be very expensive or impossible at all.

For the users with high demanding applications and low volumes a system off the shelf is seldom obtainable and a comparison between a system off the shelf and a tailored one must be carried out. This comparison is summarised in Table 1.

Besides one strong argument for the tailored system is the fact, that particular features characterise the know-how and the competitive advantage of the machine builder. By choosing a tailored design this know-how can be kept in house.

After a thorough analysis of all technical, commercial and logistics questions a decision can be taken. In the case considered here the machine builder was compelled to develop an own inverter, whose principal characteristics will be presented in the following.

System Performance: laboratory and field experience

Fig 3 shows photos of a series of tailor-made inverters, particularly designed for high dynamic multi axis drives in the power range from 90kW to 150kW.

On the control side up to 4 drives can be handled by one CPU. As the VME-bus allows multi processor usage, the number of drives may be expanded in increments of 4 by simply adding another CPU-board into the main computer rack. Using fast transfer rates over the VME bus a tight synchronisation of all drives is feasible. This art of communication offers a much better -and in this case necessary- performance compared to drive systems using standard field busses.

Having used DC drives with analogue control in the past, the first approach toward AC-drives consisted of integrating off the shelf digital vector-controlled inverters into a multi-axis drive system. All of a sudden engineering-, commissioning-, startup- and maintenance times at least tripled compared to the simple, well known DC-analogue-technology. By developing the new tailor-made drive system, a substantial progress was achieved in:

- hardware cost of inverter reduced by approx. 10%
- number of parameters per axis reduced by approx. 90%
- engineering cost per axis reduced by approx. 20%
- Startup time halved
- Maintenance time in the field substantially reduced due to less complexity of the system
- Warranty expenditure substantially reduced due to less components per drive

System	Advantages	Disadvantages
Off-the-shelf vector-controlled drive	Availability Cost service world-wide component handling	**must** be configured cumbersome to use has more functions as required for the application
Tailored drive	technique is self made no unnecessary overhead optimal electrical dimensioning optimal mechanical design	unfamiliar technology power electronics and motor know-how are mandatory

Table 1 Comparison between tailored and "off the shelf" systems

4. CONCLUSIONS

Drives and power electronics for high-demanding, high-dynamic applications require very special features for the optimisation of machines in sense of the mechatronic. In the higher torque range it is very difficult to find suitable drives on the market for this kind of tasks. Even though or especially because inverter manufacturers try to design the all-in-one device off the shelf inverters are only second best choice.

For a given high demanding application the following issues should be carefully examined :

- Low volume series of machines
- Each version „equal“ but „different“
- Multi-axis system with tight synchronisation requirements
- Deadband and overhead within control- and drive system is crucial

• Special know-how in hardware and software should be protected

If several of these items apply, the development and production of tailor-made power amplifiers should be considered.

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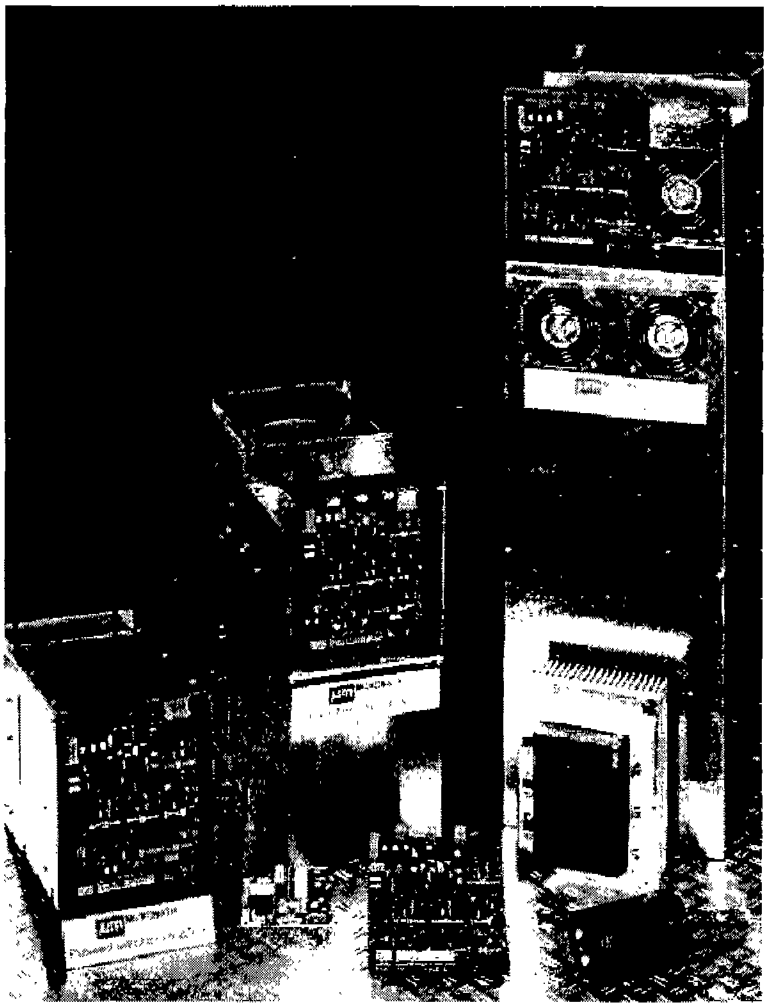

Fig 4 Inverters with modular VME industrial computer system