SIEMENS

Jens Weidauer, Richard Messer

Electrical Drives

Principles • Planning • Applications • Solutions

Electrical Drives

Principles · Planning · Applications · Solutions

by Jens Weidauer
and Richard Messer

Publicis Publishing

Bibliographic information from the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at http://dnb.d-nb.de.

This contents of this book are based on a collaboration with the sfb Bildungszentrum.
www.sfb.ch

www.publicis-books.de

Publishing editor: Gerhard Seitfudem, gerhard.seitfudem@publicis.de

Print ISBN: 978-3-89578-434-7
ePDF ISBN: 978-3-89578-923-6

Editor: Siemens Aktiengesellschaft, Berlin and Munich
Publisher: Publicis Publishing, Erlangen

Printed in Germany

Weidauer/Messer
Electrical Drives

Foreword

Electrical drives are the most important source of mechanical energy in machines and industrial plant. In our modern world, they ensure that motion can take place, and that transport and manufacturing processes are possible at all. Although the technical field of electrical drives is over 100 years old, today it is more dynamic and diverse than ever.

It starts with the electric motors themselves, the heart of all electrical drives. Today, they are not only available in the widest range of designs and power classes – from standard motors for direct-on-line operation to highly-efficient servo motors – but they also distinguish themselves through their ever more ingenious design principles and use of novel materials. Smaller, lighter, and more efficient electric motors give designers new degrees of freedom, pushing ahead the development of machines, plant equipment, and electrical vehicles.

Drive controllers are also becoming more powerful and smaller due to fast, low-loss switching power semiconductors, faster microprocessors, as well as modern manufacturing technologies. In combination with innovative electrical motors, the torque, speed, and position of electrical drives can today, at any given time, be set exactly as required by the manufacturing or transport process. In many instances, the controller and electric motor are brought together and combined in one device. In particular, electromobility is driving the development of real mechatronic systems, in which gearbox, electric motor, and drive controller merge together to provide customised drive solutions.

As part of a modern automation solution, electrical drives must be universally coordinated. To enable this, they are equipped with communication interfaces as well as integrated control, safety, and diagnostic functions going well beyond those of the classic drive controller. These allow the planner to implement the required coordination functions centrally, distributed, or in the drive itself.

Through both technical advancements and increasingly finer adaptations for special requirements, the wealth of types of electrical drives will continue to increase. Good orientation in the world of electrical drives is therefore indispensable for both decision makers and designers. This book provides this. Both the principles as well as the application of electrical drives are presented systematically and clearly. This comprehensive overview will benefit the reader and provide added confidence when evaluating drive solutions.

Now in its third edition, this "standard work of electrical drives" will continue to broaden the knowledge of electrical drives, and for many technicians be a useful guide when designing efficient machines, plant equipment, and electrical vehicles.

Prof. Dr. Siegfried Russwurm
Member of the Managing Board of Siemens AG

Contents

1 Electrical drives at a glance

1.1 A short history of electrical drives

Electrical drives convert electrical energy into mechanical energy and serve as the intermediary between the electrical supply system, the energy source, and the driven machine, the energy consumer.

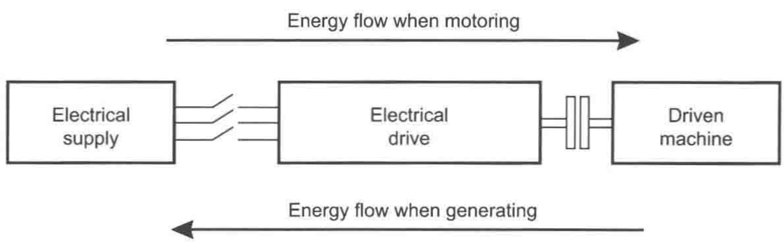

Figure 1.1 Electrical drives as the intermediary between the electrical supply system and the driven machine

Due to their central position in the energy chain flow, electrical drives have become a key component in industrial applications, as well as in transportation and in consumer goods. In many areas, they have driven technical development and have themselves been the focus of numerous developments.

The core component of every electrical drive is the motor. The physical laws, upon which the motor is based, were discovered in the early 19^{th} century.

Discovery of the principles 1820 to 1875

In 1820, Hans Christian Oerstedt discovered that when a magnetic needle is suspended close to a current carrying conductor, it is deflected. In the same year, André Marie Ampère made his fundamental discoveries of the interaction between electrical currents and magnetic fields. These discoveries led to the development of a large number of "electromagnetic machines", whose practical application, however, were limited due to the limited source of electrical energy available at the time. Current was produced by galvanic cells, which prevented the use of such "machines". They could not establish themselves against the steam engine or the many types of gas or petrol driven engines.

An important step was made in 1831. Michael Faraday discovered electromagnetic induction. This effect was immediately put to use in generators. In 1866, Werner von Siemens invented the dynamo. This direct current generator uses the magnetic remanence of the magnetic poles to initially produce a small induced current. This induced current is then used to produce an excitation field, which in turn brings the generator up to full power. Further development of these generators has given us the modern day motor.

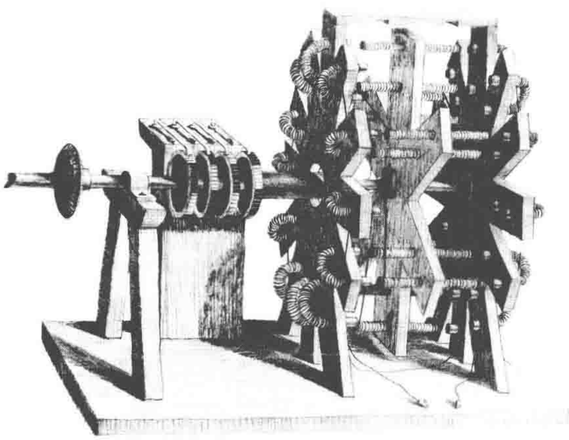

Figure 1.2 Electric motor by Moritz Hermann Jacobi, 1818.
Photograph: Deutsches Museum, Munich

Electrical power transmission 1875 to 1891

At the end of the 19th century, a central problem was supplying energy in the small quantities required for machines in light industries. Steam engines were costly to maintain and for safety reasons could not be used everywhere. Gas powered motors were therefore in widespread use. Competition came from dynamo machines, which had been continuously developed and improved. The arrangement consisted of two, electrically connected dynamo machines. One machine was used as a generator, the other as a motor. In this way, the electrical energy required could be generated at one location, transmitted over a longer distance and then, at the location where it was required, be converted back into mechanical energy. Electrical energy replaced mechanical energy as the transmission medium. The main applications were electric locomotives and street cars but also machine drives, e.g. for weaving machines, were realised.

In 1887, the term "electric motor" appeared for the first time in a sales catalogue. In 1891 the advantages of the electric motor over a steam engine and gas motor were described as being:

- they do not need a fixed foundation, can be mounted in any position, require little space, and can be used in domestic quarters
- they can be run at relatively high speeds, the speed and direction of running can be altered, they have a favourable efficiency and are easy to operate.

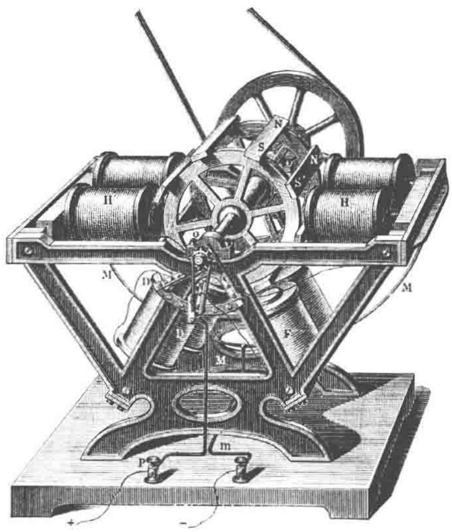

Figure 1.3 Froment's electromagnetic "mouse mill" motor (from Meyers Konversations-Lexikon 1886)
Photograph: Deutsches Museum, Munich

In 1889, Michael von Dolivo-Dobrowolski invented the three-phase squirrel-cage induction motor. It was he who coined the term three-phase electricity. Additionally, in 1891 he realised the first three-phase power transmission network, from Lauffen am Neckar to Frankfurt am Main, a distance of 175 km.

Electrical drives in commerce and industry 1891 to 1920

At the International Electrotechnical Exhibition of 1891 in Frankfurt am Main, a complete system consisting of generators, transformers, transmission cables, and motors was shown for the very first time. This was the foundation for the introduction of electrical supply networks and electrical drives for both industrial and commercial applications on a

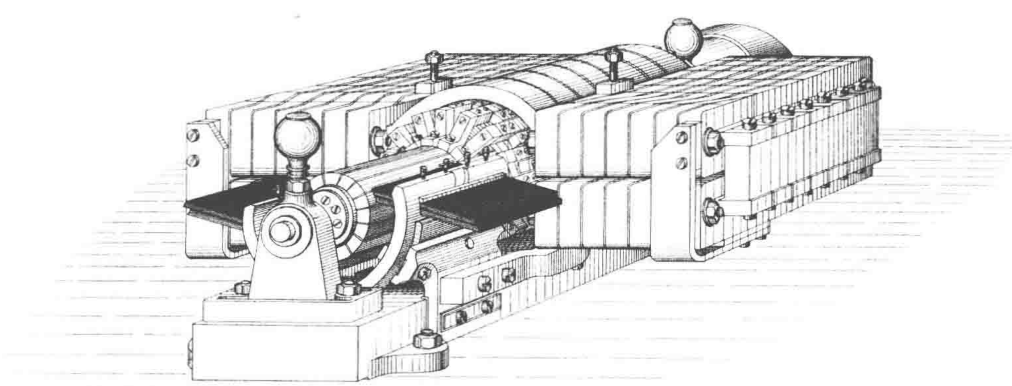

Figure 1.4 Dynamo Siemens & Halske, 1877 supplied for the Oker iron works.
Photograph: Deutsches Museum, Munich

wide scale. Electrical motors were continuously improved with regard to their technical data and their starting characteristics. With the use of resistor networks and the Ward Leonard set (a converter for altering the voltage and frequency), controllable electrical drives became available. This led to the gradual replacement of steam engines and transmission systems in workshops. The machine design could now be optimised to the needs of the manufacturing process and was no longer subordinate to the supply of energy via transmission shafts.

Electrical drives proliferate 1920 to 1950

From around 1920 onwards, electrical drives spread in to all areas of industry, farming, trade crafts, transportation, and into households. Typical drive solutions consisted of DC or AC motors, which depending on the application, were complemented with a controller for adjusting the speed. The number of electrical drives increased significantly. Electrical motors themselves developed in two directions: to integrated solutions within the driven machine, and to standardised mass products. The asynchronous induction motor became the most widely used type in industrial applications. In addition to contactor controls, the first controllers, based on mercury-vapour rectifiers, were used for variable speed applications. Power electronics had found their way into electrical drives.

Converter drives 1950 to 1970

The development of power semiconductors was the beginning of the end for the mercury-vapour rectifier. In parallel, controllers based on analogue electronic components were developed, which supported the spread of variable-speed drives. The simple controllability of DC drives led to their resurgence.

Drives with microprocessor since 1970

The introduction of the microprocessor led to a burst of development in electrical drives. Analogue controllers were replaced by digital ones. Their performance improved continuously, enabling more and more complex functions to be implemented. The development of the "field-oriented control" method by Blaschke in 1971, and its subsequent implementation in a processor-controlled digital drive, enabled AC motors to be controlled with the same control performance as a DC motor.

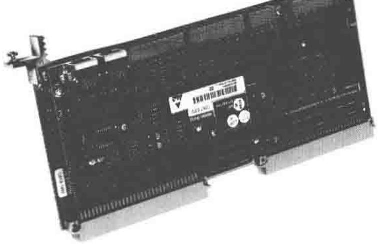

Figure 1.5 Digital control board of a DC drive

Figure 1.6 High power IGBT (Insulated Gate Bipolar Transistor) as used in a frequency converter

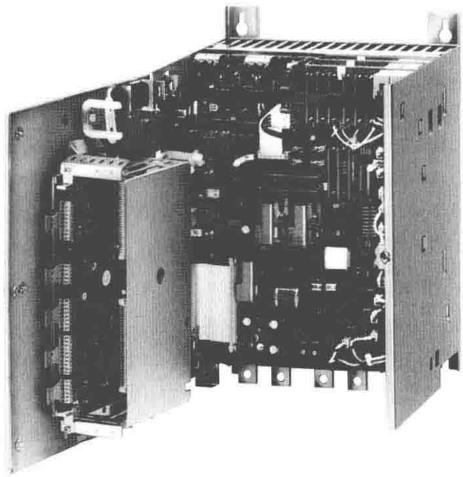

Figure 1.7 Modern digital DC drive converter

The availability of increasingly more powerful microprocessors enabled the integration of functions originally foreign to the drive into the controller. The boundaries between electrical drives and automation devices have become less clearly defined. Drive systems, which consist of electronically-coordinated low-power servo drives, are more and more replacing centralised drives with mechanical gearboxes and main line shafts.

1.2 Design of modern electrical drives

The mechanical energy supplied by the electrical drive is used to control the process variables in the driven machine. The mechanical energy must be adjusted or switched on and off to the process needs. For this reason, a modern electrical drive consists not only of an electrical motor but also a host of additional components (see Figure 1.8).

Electric motor

The heart of every electrical drive is its electric motor. It acts as an energy transformer, converting the electrical energy supplied to mechanical energy. In generating operation, e.g. when braking, the energy flow is in the opposite direction: mechanical energy is then converted back into electrical energy.

Motor encoder

A motor-mounted encoder (motor encoder) determines actual quantities such as rotary speed, speed, and position and makes these available to the signal electronics.

Brake

A brake assists the controller in braking the motor and prevents the motor from moving when the controller is switched off. Particularly when handling suspended loads, e.g. robotic arms, elevators, and hoists, the brake holds the mechanical system tight even when the drive is inactive.