Mobile Electric Power Supply for Agricultural Machinery and Implements

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Abstract

Modern agricultural machinery is characterized by high efficiency and best performance in controllability of the used power drives. As machines are equipped with electronic components, in most cases integration in the electronic control system is claimed. So far power drives have been realized by direct mechanical or hydraulic drives. But electric drives have made much progress in power density, speed and torque control and integration in control systems. The development of permanent magnetic synchronous motors and sensorless speed control combined with power electronics provide new possibilities in the design of power drives. Thus, advantages in the application of agricultural machines can be gained.

This paper gives an introduction to electric power drive technology. Advantages and disadvantages of new drive trains will be presented. A whole system, which is necessary for a high performance electric drive, is explained. Examples of already performed and available systems are given. A concept of a flexible mobile electric power supply will be presented, which can be used for both several implements and emergency power supply as well.

The introduction of a new source of power on the tractor requires a change of the whole power distribution system. Future tractors may not only offer hydraulic and mechanical power but may also be equipped with an electric power socket. The development is accompanied with many open questions and requirements, such as type and level of voltage, safety concept, electrical isolation, electromagnetic compatibility and so on. The paper will be completed by a short outlook of possible future solutions.

Keywords: Electric drives, electric power supply, pto generator

1. Introduction

An important trend in agricultural engineering is the increasing complexity and power demand of the used machines. Modern agricultural machines are characterized by high efficiency and best performance in controllability of the used power drives. In the past power drives were realized only by mechanical drives. The efficiency of a direct mechanical drive with only simple gear steps cannot be beaten. With the increasing demand of speed variability, hydraulic power was introduced. Due to low efficiencies of the hydraulic system (pump-motor) at the beginning, worse system efficiency had to be accepted. Extensive development and the introduction of special solutions, like the mechanical-hydraulic power split, have led to an impressive increase of the efficiency coupled with best performance.

However, due to the increasing driving power of agricultural machinery and high fuel prices in recent years, the efficiency of the whole process has reached very high priority. This means that:

- the efficiency of single power drives has to be improved
- speed variation is more and more necessary to optimize the power requirement
- an integration of all implement functions in the electronic control system of the tractor / vehicle is necessary

In the last years electric power drives underwent a strong development. New and high integrated electronic components, e.g. power transistors, were the basis for powerful electronic controls. Furthermore, the development of very compact electric engines with a high power density opened new possibilities in the design of power trains. That is why, electric power drives became more and more interesting, not only in automotive but also in agricultural engineering.

2. Modern Electric Power Drive

The main parts of a modern electric power drive are the electric motor with an encoder for speed / position detection, a mechanical gear unit for speed/torque adaption, a frequency inverter and a programmable logic control (PLC) (*Figure 1*).

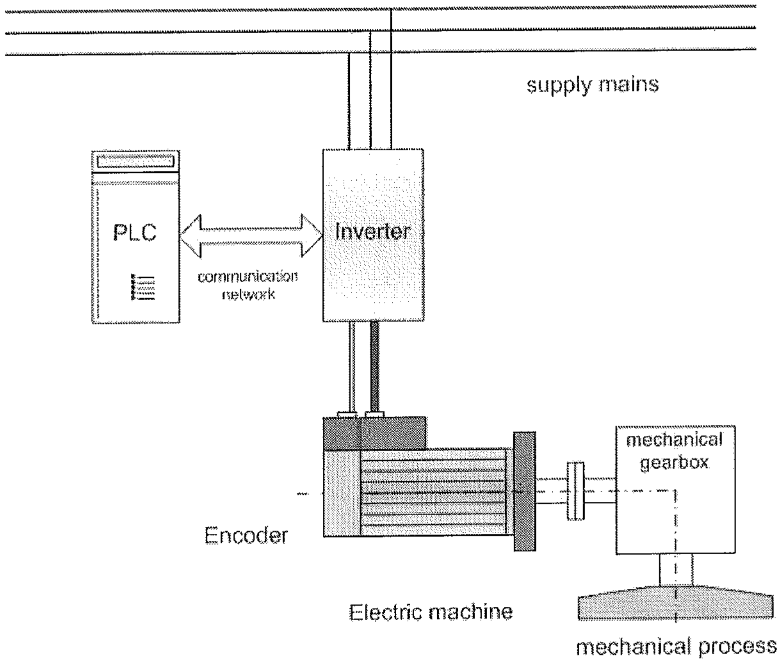

Figure 1: Scheme of a modern electrical drive

The heart of a power drive is the electric motor. In former times the electric machines were classified according to the type of voltage source in single phase a.c. motor, three phase a.c. motor or d.c. motor. Due to the use of power electronics (inverter technology) each voltage source can be transformed into a voltage which is necessary for the individual electric motor. That means there is a wider range of motors which can be used. The following Table 1 reflects the most important electric machines with their main properties which can be used for power train purposes.

Table 1: Main types of electric motors

type	characteristics
AC induction motor (asynchronous motor)	least expensive, long lifespan, high power; low starting torque
AC synchronous motor	very high power density, high efficiency, high starting torque, long lifespan, more expensive, only with control
stepper DC motor	precision positioning, high holding torque
brushless DC motor	long lifespan, low maintenance, high efficiency
brushed DC motor	low initial cost, simple speed control, maintenance necessary; typical 12V or 24V applications, limited power output

In comparison to standard electric motors of former times (like typical three phase asynchronous motors which are used as electric drives in agriculture) modern electric machines have a much higher power density. Due to the high flexibility in choice of the motor type and the use of power electronics nearly all drive train requirements can be covered.

Electric motors are typically operated at high speed to receive a little diameter, low moment of inertia and high dynamic properties. A gear unit is necessary in most cases to adapt speed and torque. But it is also possible to design direct and gearless drives with engines operated at low speed with very high torque. The space requirements are often lower and the integration is easier. For instance, the construction of permanent magnetic motors can also be performed as an outer rotor (Figure 2). The electric parts of the motor can be integrated in a tube or cylinder which saves space enormously.

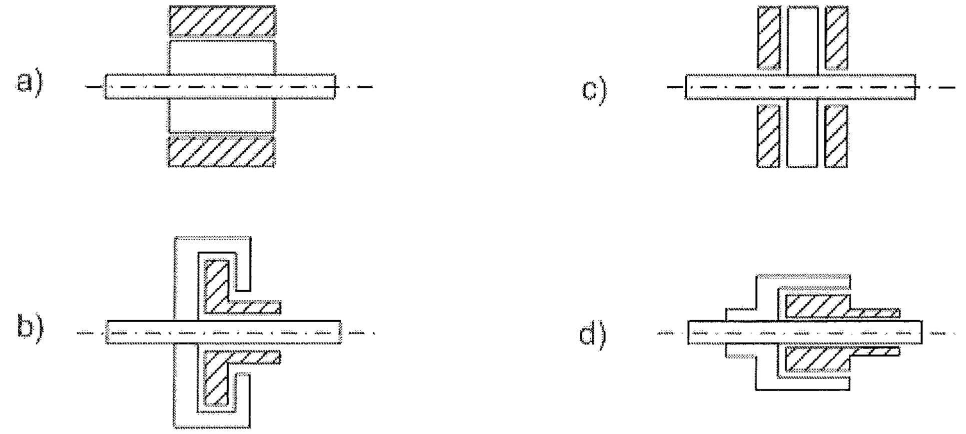

Figure 2: constructive variation of permanent magnetic synchronous motors
a) inner rotor b) shrunk-on-disk stator c) shrunk-on-disc rotor d) outer rotor

A modern power train must be able to control speed or even rotation angle or machine position of the application. Usually an encoder is used. Much research was put in the development of making such encoders unnecessary. Schroedl [1] [2] has developed the INFORM-method for sensorless detection of the machine position even at low speed and standstill and an EMK-method for detection of the position at high speed. The method can be used for building up a power drive with a permanent magnet synchronous with best performance.

The frequency inverter (Figure 3) consists of three main parts: a rectifier which converts the a.c. input voltage into a d.c. voltage, the intermediate d.c. circuit and an inverter module which converts the d.c. voltage into a frequency and amplitude controlled three phase a.c. voltage again. The main parts of the inverter module are electronic switch components (power transistors, in most cases insulated gate bipolar transistors IGBTs). The torque of the motor depends on the current which is controlled by the inverter. Speed and torque can be controlled infinitely until standstill. For a short time a breakdown torque can be provided which is much higher (2-3 times) than the rated torque. As the current drain has to be measured as input for the control unit, a parameter for torque, speed and thus power is available anytime. The use of power electronics also allows four quadrant operations.

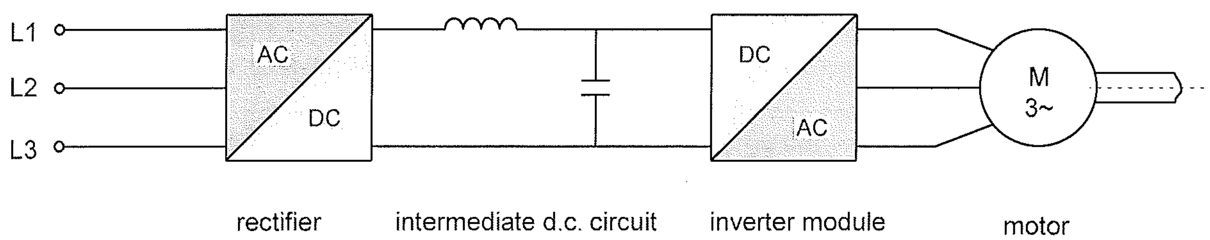

Figure 3: Frequency inverter

In 2009 new efficiency classes were defined for electric motors [3]. Beginning with 2011 all electric motors have to fulfil the IE2 efficiency level: The minimum efficiency for a 4pole/15 kW motor is defined with 90.6%, for a 55kW motor with 93.5% for instance. Beginning with 2015 the motors have to fulfil IE3, increasing the efficiency to 92.1 (4pole/15kW) and 94.6% (4pole/55kW). Respecting the efficiency of modern inverters, the whole efficiency of a well designed electric power drive with approx. 50 kW can be assumed higher than 88%.

3. Electric Power Drive Projects in Agricultural Engineering

Electric power drives have been interesting for a long time. Over the years different projects have been realized demonstrating prototypes of power drive concepts or even whole machines or vehicles. In the following overview examples are selected without claiming completeness:

- The ELTRAC project [5] was an initiative of P.J. Schmetz GmbH in Germany. A 100 kW tractor, type New Holland M135, was converted to a full serial hybrid. Powershift and auxiliary transmission were replaced by an electrical power drive.
- The ProHybrid EECVT [6] project of Case IH was shown at the Agritechnica exhibition in 2005. A 120 kW Case MXM tractor CVT with 800 Nm torque was converted to a full hybrid vehicle. A 50 kW generator supplied a 50 kW electric motor with 456 V DC and a battery with 11.5 kWh.
- In 2001 the FH Regensburg started with the MELA-Project demonstrating a powerful hybrid concept [7]. An internal combustion engine drives a permanent magnetic synchronous generator with 3500 rev/min (primary machine). The 130 kW generator supplies an open DC grid with 540V. Two identical secondary machines are used as a power drive for an electrical / mechanical power-split gear drive. The open DC network could be the power source for many or even all power drives of the system.
- The powerMELA® concept of STW [8] describes a mobile electric power and hybrid system for mobile vehicles and machines. An intelligent hybrid drive system can be realized with electric power for auxiliary systems and external loads. Very important is the protection and safety concept which ensures safe transmission of electric power. The technical data are impressive: power output of the motor 140 kW at 3000 rev/min, torque 450 Nm, up to 750 V DC, IP65, 4-quadrant operation, weight 130 kg, fluid cooling, dimensions: ∅ 440mm x 290mm x 405mm.
- At Agritechnica 2007, John Deere presented the E Premium 7000er series [9]: A crank shaft starter generator with 20 kW at 1800 rev/min supplies the on-board electric system (12V, 300 A max) as well as the power drives of the cooling pump, cooling van and air conditioning compressor. The drives are fully speed controlled and thus run with high efficiency. The power management system can support the diesel engine with 7.5 kW electrically. Furthermore, the tractor is equipped with a 5 kW power socket (230V/16A and 3x400V/16A) which is available during standstill. The tractor is available in the market in the meantime.
- Also at Agritechnica 2007 the Rauch company presented the Axis-EDR, an electric driven fertilizer spreader. The spreader disks are powered by two 10kW / 400V

electric motors which are controlled by the tractor. Agitator and dosing are powered by the tractor's 12V DC electric system.

- The Belarus company presented at Agritechnica 2009 a 220kW standard tractor with a diesel-electric power drive. The front pto (power take off) is electrically powered and thus independent from engine speed. Up to 172 kW of electric power can be provided for external use.
- Amazone presented a field sprayer type UX eSpray which is fully electrically powered with a demand of 17 kW at 400V: The system comprises an infinitely variable sprayer pump, electric agitator, electric valves, electric clear water pump, electric powered hydraulic system for boom and steering control.

Furthermore studies and examples can be found in literature, like the infinitely variable pto transmission of John Deere presented at the VDI AgEng conference 2009 [10], a tangential threshing cylinder with integrated electric drive (TU Dresden, VDI AgEng conference 2009 [11]), electrically assisted power trains for agricultural machinery (ZF Friedrichshafen, VDI AgEng conference 2009, [12]) or a first diesel-electric powered bulldozer (Zeppelin GmbH, VDI AgEng for Professionals 2010, [13]).

4. Concept of Mobile Electric Power Supply

It can be assumed that application of electric drives in agricultural machines and implements will increase in the years to come. Furthermore, it can be expected that future tractors will not only provide mechanical and hydraulic but also electric power which was already shown by John Deere in 2007 [9]. In the meantime a reliable and flexible mobile electric power source will be needed. That is why Francisco Josephinum / BLT Wieselburg, together with the Vienna University of Technology and the company High Tech Drives in Austria started with the development of a universal mobile pto generator.

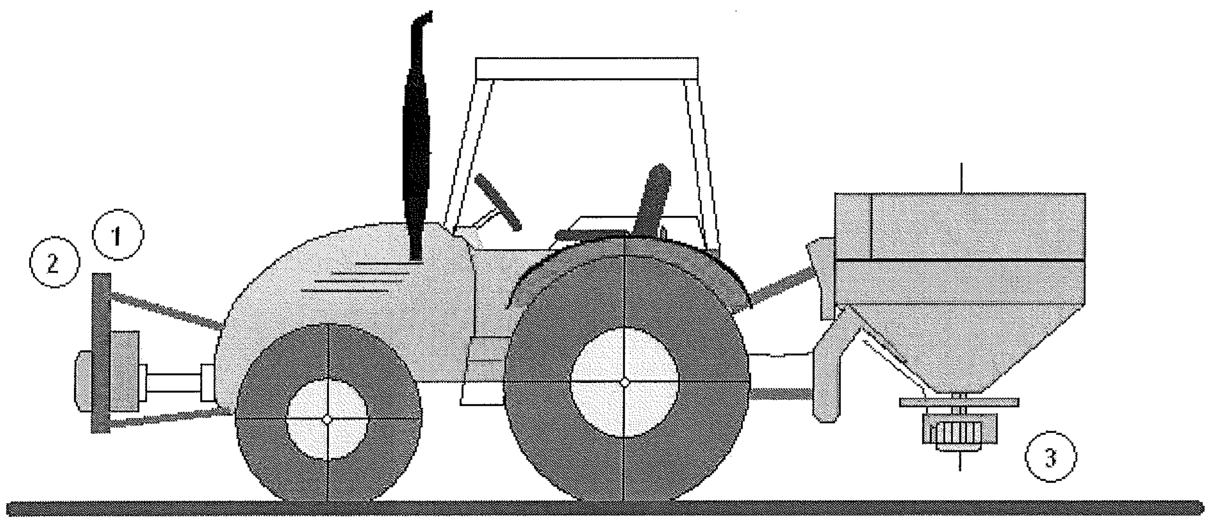

Figure 4: concept of a flexible mobile power generator
① generator ② power electronics ③ electric motor

The concept envisages a generator being mounted and operated by the front pto (Figure 4). In principle the system can also be applied directly at the implement. The generator is equipped with the necessary safety devices. The permanent magnetic synchronous machine is air cooled and produces 15 kW at 1000 rev/min (Figure 5). It generates approx. 450 V a.c. at rated speed and is composed with tooth coil technology. The machine is characterized by the following properties: high torque per volume ratio (or torque by mass), short circuit strength, ability of being controlled with sensorless methods down to standstill (INFORM® method) and overload up to three-times rated current. The motor is air-cooled and can preferably be used in direct drives for industry and traction [4].

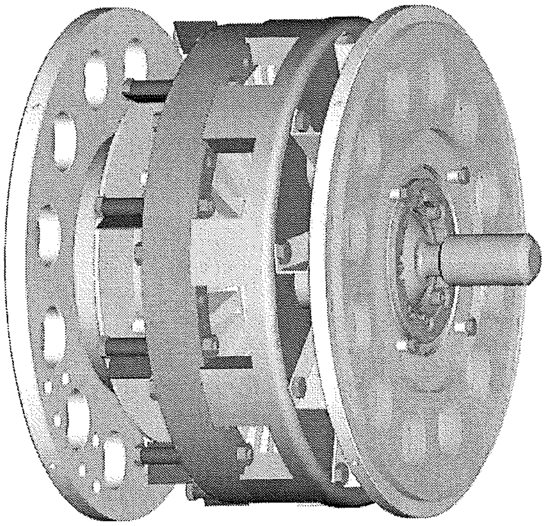

Figure 5: drawing of the electric machine of the pto generator

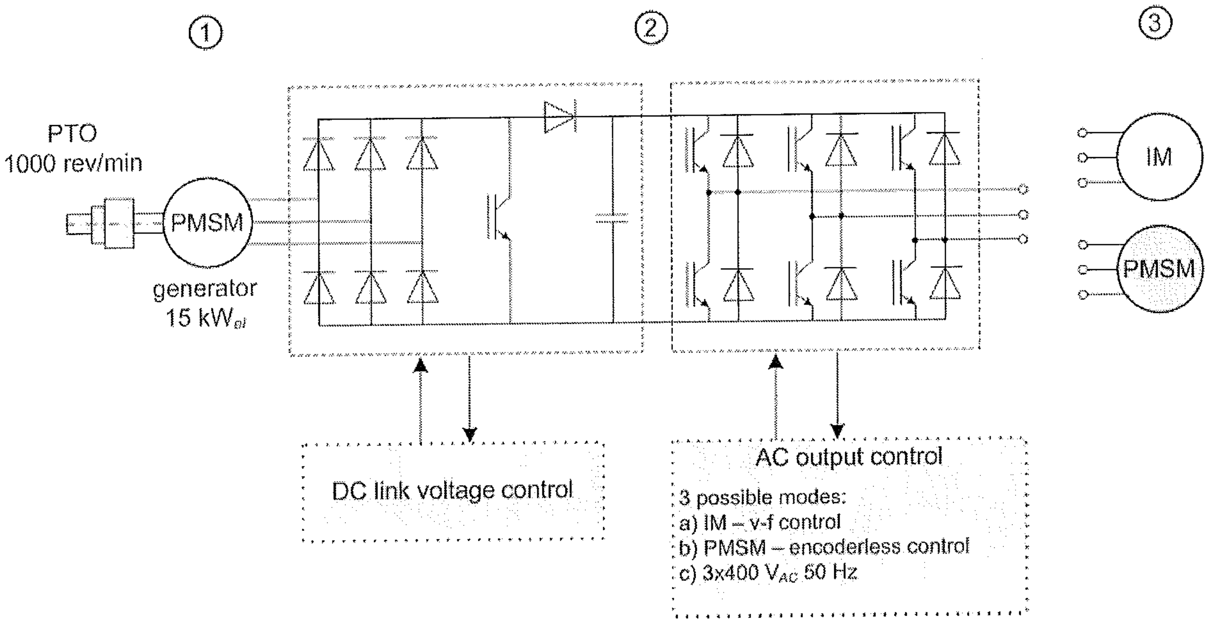

Figure 6: electric scheme of the pto generator

The electric scheme of the system is shown in Figure 6. The generator ① is equipped with power electronics ② and can produce electric voltage for different applications ③. Three modes are possible:

- mode (a) supplies a controlled voltage which can be provided for the operation of one or several asynchronous machines (induction machines IM). Speed value is variable and can be adjusted by a simple terminal,
- mode (b): Instead of an induction machine also a permanent synchronous motor (PMSM) or brushless DC motor can be used. Although speed and torque control is available, no further speed sensor is necessary (sensorless speed control). System set up and speed adjustment can be done by a terminal which is compatible to ISOBUS, optionally,
- mode (c) is only for stationary application: The generator produces a fully controlled 3x400V 50 Hz voltage for emergency or off-grid applications.

5. Possible future developments

Especially self-propelled harvesting machines like the combine harvester, chopper or potato harvester with complex and different driving systems and a high number of rotating parts will be investigated. Low efficient mechanical or hydraulic power drives will be replaced by electrical ones. The electric power source will be produced by a generator operated directly by the internal combustion machine, preferably by an integrated starter/generator system. If sufficient power is available, mild or full hybrid systems can be realized. As there is a closed electric system there is no further problem with standardization concerning external demands.

The technology will also be interesting for implements with many different drives. The advantages of infinitely variable transmissions will lead to new solutions and optimization of agricultural working processes. The electric power could be provided by a generator mounted on the implement itself which is powered by the tractor's pto or by a mobile pto generator as presented in the paper. The system is comparable with an individual hydraulic system which can be found at several implements today. In this case there is no further need for interchange of energy or information with the tractor. Although the implement can be optimized itself, the possibilities are limited.

Most interesting solutions are conceivable if the tractor itself is able to provide sufficient electrical power. The internal power distribution of the tractor can be optimized, hybrid driving is possible and an infinitely variable pto transmission is no further problem. The tractor of the future is equipped with an electric power socket and can supply the implement with a frequency and amplitude-controlled voltage. Most attention has to be put on safety requirements, standardization and cooling as well.

6. Summary and Conclusion

This paper describes the functionality and properties of a modern electric power drive. Due to the use of power electronics and the great variety in construction, electric drives can be used very flexibly. Very high efficiency and best performance are possible with permanent magnetic synchronous motors together with power electronics. New solutions do not need a speed encoder anymore which simplifies the application. The integration in an existing control network can be done without great efforts. The electronic system is able to provide data about speed and torque which enables an optimized process control.

Many projects and prototypes of electric power drives have already been shown in agricultural engineering in recent years. It can be assumed that new applications or even commercial products will follow in future. Thus, a powerful and flexible voltage source is crucial up to the point when the tractor will provide electric energy. In the paper a flexible and mobile pto generator is presented.

Electric power drives could be applied to self-propelled harvesting machines because of the complex driving system and the high number of rotating parts. If electric motors are used on implements, the power supply could be generated by the implement itself or by a mobile pto generator. It can be expected that future tractors will be equipped with an integrated powerful electrical generator and will provide electric power for external use.

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