Multi-Functional PTO Generator for Mobile Electric Power Supply of Agricultural Machinery

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Abstract

A high efficiency and optimal performance in controllability are the most important requirements of power drives used in modern agricultural machines. As many implements are already equipped with electronic components, the integration in the electronic control system of the tractor is claimed. So far power drives have been realized by direct mechanical or hydraulic drives. But meanwhile electric drives provide new and suitable properties, like a high power density, speed and torque control and all necessary interfaces. Thus, the importance of electric power drives in agricultural engineering is expected to rise in future. But, until sufficient electrical power is installed on tractors, there is a demand for a mobile electric power supply.

A mobile multi-functional pto generator was developed by Vienna University of Technology together with HighTechDrives GmbH and BLT Wieselburg in Austria. The system can be used for asynchronous motors and encoderless operated permanent magnet synchronous motors as well. At standstill an emergency or equivalent power supply is possible. The generator's properties and performance characteristics are described in the paper.

1. Introduction

Modern agricultural machines are characterized by a high efficiency and best performance in controllability of the used power drives. Because of advanced functions speed variability is required in many applications. Hydraulic systems which provide a high power density and sensitive controllability play an important role in agricultural engineering but show sometimes bad efficiencies. Due to the increasing driving power and high fuel prices in recent years, the efficiency of the whole process has reached a high priority. On the other hand, electric power drives underwent an impressive development in the last years. High efficiencies,

considerable power/volume ratio, excellent controllability and an easy integration in the electronic control are very useful properties for applications in agricultural engineering.

An electric power drive consists of an 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. Depending on the application and type of voltage a wide range of electric motors with different properties can be used. Due to power electronics each voltage source can be transformed into the type of voltage being required by the power drive. AC induction (asynchronous) motors are commonly used. It is characterized by a simple build-up, a long lifespan, least expensive but a low power/volume ratio. In comparison a modern permanent magnet synchronous motor (PMSM) has a much higher power density and efficiency but can only be operated with a control. In most modern automotive applications (hybrid and full electric cars) PMSM are used.

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 many cases to adapt speed and torque. The construction of permanent magnet motors can also be performed as an outer rotor. The electric parts of the motor can be integrated in a tube or cylinder which saves space enormously. Furthermore the duty cycle plays an important role. If the motor is used in short time or intermittent periodic duty (S2 or S3) instead of continuous duty (S1) the space requirements can be reduced significantly.

A modern power train must be able to control speed or even rotation angle or machine position. 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 encoderless detection of the machine position even at low speed and standstill and an EMK-method for detection of the position at high speed. 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 4- quadrant operations.

2. Electric Power Drive Initiatives in Agricultural Engineering

In recent years an increase of projects and prototypes using electric power drives could be observed in agricultural engineering. It reflects the rising interest of the industry expecting that new applications or even commercial products will follow in future. In the following overview some examples are selected without claiming completeness:

- powerMELA® concept of STW, a mobile electric power / hybrid system for mobile machines with 140 kW at 3000 rev/min, fluid cooling
- Electric drivelines for header and intake system of a Krone forage harvester by TU Muenchen [9]
- E Premium 7000er series of John Deere with a 20 kW crank shaft starter generator (Agritechnica 2007)
- Rauch Axis-EDR fertilizer spreader with electric powered spreader disks, 10kW, 400V (Agritechnica 2007)
- 220 kW diesel-electric tractor of Belarus with electric front pto and up to 172 kW of electric power for external use (Agritechnica 2009)
- UX eSpray of Amazone, a fully electrically powered field sprayer with a demand of 17 kW at 400V
- tangential threshing cylinder for combine harvesters developed by TU Dresden (VDI 2009, VDI 2010 [3])
- Terra+ integrated generator hybrid system of ZF for agricultural machines [4]
- diesel electric powered bulldozer by Zeppelin GmbH [5]
- Powerpack systems and opportunities in mobile agricultural machines [6]
- E-RoGator self propelled sprayer with electric drivelines of Agco [8].

There is a serious aim of the AgEng industry to force the development of electric drives which can be derived from the AEF activities. Within AEF, the Agricultural Industry Electronics Foundation, a project group “High voltage” was founded in spring 2011 [7] aiming at developing a specification for a tractor implement interface [10].

3. Multi-Functional PTO Generator

If electric drives will be applied on implements a powerful and mobile electric power supply is necessary. Vienna University of Technology and High Tech Drives GmbH together with BLT Wieselburg, Austria, developed a mobile multi-functional pto generator. The concept envisages a generator being mounted and operated by the front pto but could also be

applied directly at the implement. The generator is equipped with the necessary safety devices.

The permanent magnet synchronous machine is composed with tooth coil technology and is air cooled. The current power output is 15 kW at 1000 rev/min approx., 450V a.c, but can be doubled without changing the overall dimensions. The machine is characterized by a high torque per volume ratio (or torque by mass), short circuit strength and overload up to three-times rated current. The machine can be controlled with encoderless methods down to standstill (INFORM® method) [2].

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

- v-f controlled voltage for asynchronous machines (induction machines IM), variable speed value adjusted by a terminal
- permanent magnet synchronous motor (PMSM) with speed and torque control, encoderless
- stationary application: fully controlled 3x400V or 1x230V 50 Hz voltage for emergency or off-grid applications.

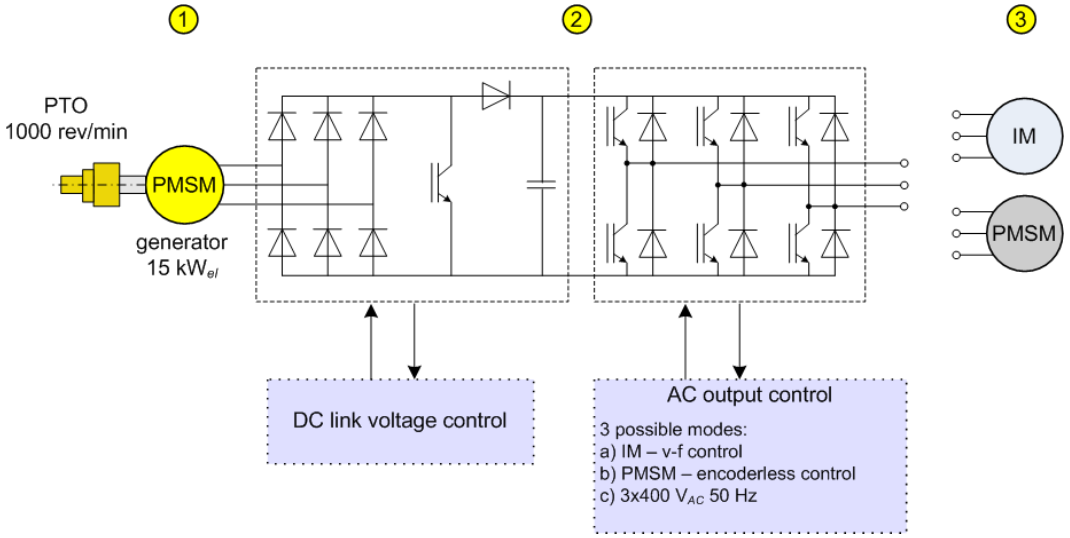

Figure 1: electric scheme of the pto generator

Figure 2 shows the pto generator operated by the tractor's front pto. The generator supplies an electric swather. PMSM are used for both, the generator as well as the swather. Both

machines are operated encoderless. The system was presented during the Kolloquium “Elektrische Antriebe in der Landtechnik”, July 2011 in Wieselburg, Austria [10].

Figure 2: tractor with electric swather powered by the multi-purpose pto generator

4. Test Results

Power load tests were carried out with the generator on the test bench of Vienna University of Technology. Figure 3 shows the open circuit voltage which is linear depending from the machine speed. As the pto speed is variable the intermediate voltage has to be controlled by the DC link voltage control. The generator shows a high efficiency of 94% in a wide range of load. Even in part load (>20% load at low speed, > 60% load at high speed) the efficiency is more than 90% (figure 4).

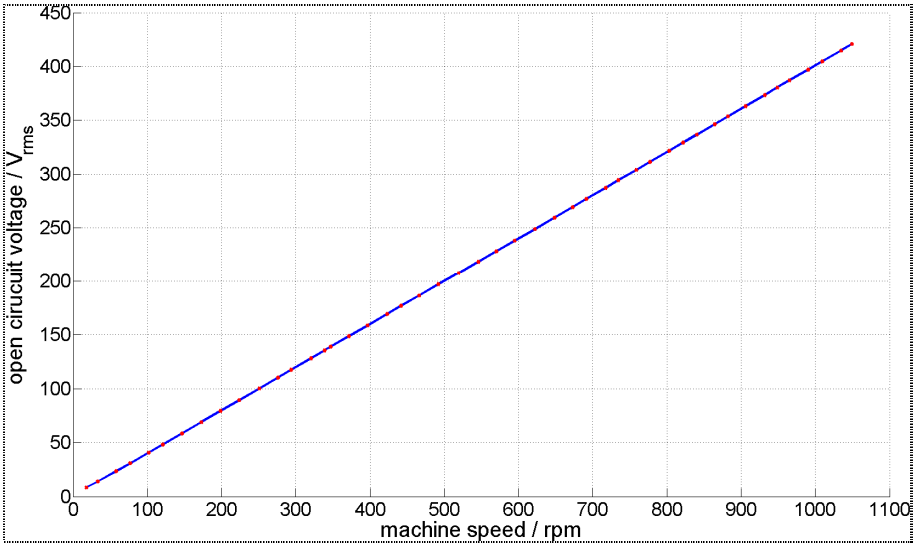

Figure 3: Open circuit voltage vs. machine speed

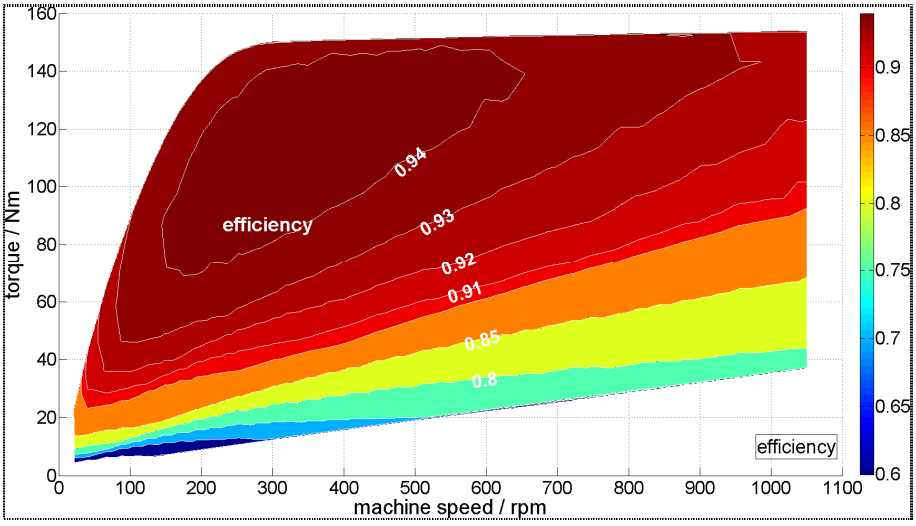

Figure 4: Efficiency characteristic

5. Summary and Conclusion

The functionalities and advanced properties of a modern electric power drive are described. Very high efficiency and best performance are possible with permanent magnet synchronous motors together with power electronics. The electronic system is able to provide data about speed and torque which enables an optimized process control. Technology for encoderless operation is available.

In recent years an increasing number of electric power drive projects could be observed, expecting 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. Vienna University of Technology, High Tech Drives GmbH and BLT Wieselburg have developed a multi functional pto generator showing a high efficiency of 94% in a wide load range. The generator provides v-f controlled voltage for induction machines, permanent magnet synchronous motors (encoderless operation) and 3x400V 50Hz for stationary application. First tests were carried out on the test bench and in the field.

Much force is put into the specification of a tractor-implement interface for an electric power supply: Within the AEF, the Agricultural Industry Electronics Foundation, a project group “High Voltage” was founded aiming at specifying the interface, system performance and safety. 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.

7. References

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