

Electric drives in agricultural machinery - approach from the tractor side

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1. Introduction

The need for agricultural equipment caused by increasing world population is more than obvious. Current agricultural equipment has reached its optimization limits in terms of complexity and efficiency with the current technology. Furthermore improvements in the area of drive technology currently mainly mechanical or hydraulic drives are limited. Therefore the focus in this area will be on electrical drives in the future.

2. Why electric drives on agricultural machines?

Vehicles in agricultural applications currently use 14V electricity only for on-board use. Introduced at the 2007 Agritechnica Fair a high voltage system was added to an agricultural vehicle, the John Deere E Premium tractor. This new system provides power to electrically driven engine auxiliaries. In addition to that intelligent control of auxiliary drives helps to reduce the fuel consumption of the vehicle especially under part load conditions, just driving the auxiliaries at the actual required power level.

The E Premium tractors represent the first high power electrification approach in series production within agriculture and already represents a catalyst for further electrification in agricultural equipment.

The main drivers for the usage of higher voltage on agricultural machines are:

- Optimized controllability of power flows across agricultural machines and between machines
- Generate sufficient electrical power
- Reduced parasitic loads caused by engine auxiliaries to improve complete machine efficiency
- Increased flexibility in arrangement of components
- Increase productivity and operator comfort

3. A short excursion into the history of electric drives in agriculture

There were several approaches to establish electric drives in agricultural machines. Some examples without intention to be exhaustive are listed below:

In 1954 International Harvester introduced a feature called Electrall to the market. This feature was offered as an option on the Farmall 400 Tractors and should support electrically-operated farm equipment and accessories. The system, co-developed with General Electric, consisted of a 208 V 10 kW three phase alternating current generator connected with cables to the device to be powered. The generator could be also used as a power generation unit. The possible applications of Electrall power were many, but few made it to market. IH marketing materials showed a haybaler being Electrall powered (**Fig. 1**). One of the more novel applications of the Electrall was a device to electrocute insects in the field at night [4] [5].

In the late 1990s a tractor with an electric generator-motor combination placed in between the diesel engine and the transmission was developed by farm equipment dealer Schmetz in Germany. This

tractor was focused on creating an infinite variable speed transmission with electrical instead of hydraulic drives used.

Beginning 2000 a concept study supported by Universities and Organizations in Germany as well as Fendt (AGCO) called MELA (Mobile Elektrische Leistungs-und Antriebstechnik; Mobile electric power train technology) has shown a possible solution on tractor electrification with electric driven auxiliaries as well as electric CVTs and implement electrification [2].

4. Areas of tractor electrification

The areas of electrification using higher voltage could be divided into four groups:

- Engine auxiliaries
- Traction drives
- Energy storage for electric drives
- Implement electrification

This report will focus on the tractor mounted parts – mainly engine auxiliaries – and mention the others only briefly. Detailed information about implement electrification is part of an additional key note report at the same meeting.

5. Engine auxiliaries

Main focus will be on drives or functions requiring high power like an engine radiator fan, an A/C compressor, an air brake compressor and an alternator.

The major benefits are performance, productivity, efficiency and flexibility in component arrangement.

Indirect benefits on tractors are:

- Possibility of power increase
- Enhanced boost power curve
- Improved transport acceleration that enhances productivity
- Increased load response in field PTO work
- Lower fuel consumption
- More comfort (electric driven A/C compressor)

These benefits could be also possible with other self propelled machines while some benefits might not apply to them.

The design criteria that affect almost all engine auxiliaries are:

- Space requirements
- Mobile environment capability
- Power density
- Cooling requirements
- Re-use of already available components

- Efficiency
- Safety

5.1 Generator

The electrical power required has to be provided by a generator. A possible place to add a generator into a conventional power train is to mount it directly to the flywheel. A crankshaft driven generator is shown in **Figure 2**. On the E Premium tractor an asynchronous (AC-induction) generator has been chosen, offering 20 kW from 1800 RPM. The generator's water jacket is connected to the tractor's engine cooling circuit. The integration with the diesel engine optimizes the space required and avoids the need for additional coupling devices. A modular concept allows re-using most of the parts in this area on non-electrified tractors too.

Alternative mounting areas are also possible. A transmission mounted generator has been developed by ZF and was on display at Agritechnica 2009 (**Fig 10**). This generator is offered in two sizes: 50 kW and 70 kW rated power depending on the selected e-machine size.

A Belarus 3023 prototype was shown at Agritechnica 2009, a tractor with a 220 kW diesel engine and a 172 kW generator, a diesel-electric drive train and an electrically driven front PTO (**Fig. 3**). This tractor gained a DLG medal representing the first agricultural tractor with diesel-electric drive train in series production. Only having an electric power transfer between the engine and the transmission, this arrangement is also suited to be operated as a stationary source for electric power, a 172 kW uninterrupted power supply for remote areas.

Using the generator also as a starter is discussed in Chapter 5.6a.

5.2 Fan Drive

The fan drive is auxiliary parasitic consume with the highest power needs. Controlling the fan drive electrically therefore creates the highest benefits from a fuel consumption impact's perspective. The fan drive power consumption varies from zero speed when no engine cooling is needed up to maximum speed under full load conditions in hot environments. A possible placement is in the area the alternator used to be (**Fig. 4**). This space on E Premium tractors now is available as the alternator is substituted by a DC/DC converter incorporated into the control unit (see also Chapter 5.5). The fan drive is designed as asynchronous electric drive, running on 480 V and has a rated power of 10 kW. The drive speed is controlled via the engine controller. Cooling requirements effected by the diesel engine, the charge air cooler, the transmission, hydraulic systems and the power electronic units are considered into the algorithm.

Reversing the air flow through the radiator for cleaning purposes by reversing the electrical drive is a by-product that is well appreciated.

5.3 Air Brake Compressor

The air brake compressor – an engine auxiliary with cyclic demand of power comes with significant idling power requirements. On E Premium tractors an electrical actuated clutch connects the air brake compressor to the electric fan drive according to the needs. Two pressure sensors located inside the air pressure tank provide the information for the controller. Being disconnected from the diesel engine also allows the compressor to fill the tank faster than on mechanic driven systems especially when the diesel engine is running on low idle and the electric drive is running on maximum speed.

Using an electric drive separate from the electrical fan drive is also a possibility and has to be reviewed in consideration of availability of electrical drives in this power range and space requirements for a separate drive.

5.4 A/C Compressor

On conventional tractor engine auxiliary concepts the A/C compressor is connected to the belt drive via a magnetic clutch. An electrical powered A/C compressor allows a more flexible arrangement of the components. The electrical driven A/C compressor (**Fig. 5**) on the E Premium tractor – mounted beside the cab – incorporates a synchronous permanent magnetic electric drive inside the compressor housing. It has a rated power of 5 kW. The more flexible location allows reducing the length of the connection lines with positive effects in terms of losses reduced. The independency from the diesel engine speed allows operating the A/C compressor at full load even when the tractor is running on low idle and creates comfort conditions faster than a conventional system is able to do.

5.5 Alternator

Availability of adequate power generated by the crankshaft mounted generator allows for the substitution of a conventional alternator with a DC/DC converter easily integrated into the power electronics. This alternator replacement is able to exceed the current limitations given by using common 14 V belt driven alternators – leading to significant efficiency improvements. On E Premium tractors the DC/DC converter was designed to provide continuously up to 300 Amps. This creates 50% more Amps compared to the state of art 14 V alternators on tractors in the 200 HP power range. Charging will now be possible following the recommendations for optimum charging the battery provided by the battery supplier. This reduces the risk of damaging the battery by overloading and ensures optimum charging at low temperature conditions.

5.6 Areas of higher power consumption on agricultural self propelled machines – not yet in production

5.6a Starter

Generator-starter concepts have been seen on hybrid cars or offered by automotive suppliers. Concept studies like ZF Terra+ [6] and the MELA Concept [2] introduce this functionality on tractors. This feature comes together with the need of having a higher voltage battery on board as well as a generator designed to provide high start torque.

5.6b Hydraulic pump

The high power needs of currently used hydraulic pumps and the good controllability of the mainly used axial piston pumps limits the opportunities for to electric driven hydraulic pumps.

5.6c Liquid coolant fluid pump

Liquid coolant fluid pumps are part of the cooling system. They also could be driven electrical. This makes the location more flexible and releases the belt drive from another component. In most conditions the power requirements could be satisfied by the conventional 14 V on-board system but

running out of a higher voltage system might be possible. Availability of components will support the decision on what voltage specification on this pump drive will be used.

5.7 External power for hand tools

With higher voltage on board it is possible to offer electrical power as shown on **Figure 6**. On tractor standstill the operator will be offered one 3 phase 400 V and one single phase 230 V power plug. If needed, both voltage and frequency could be adjusted to the county specific needs. These power outlets are rated to support handheld tools up to 5 kW power consumption. Several applications are possible. Customers have used them to repair machines in the field using an electrical weld tool or a drill. Others have shown interests in cutting hedges with electrical hedge cutters running on 230 V.

5.8 Control Units

The control units on E Premium incorporate the system controller and the power electronics – a set of inverters to generate the voltage and frequency required for the respective units (**Fig. 7**). The DC/DC Converter is also located inside one of these units. The electric drives are designed for 480 V rated voltage, the internal DC link is therefore rated for the corresponding 700 V DC. The control units are liquid cooled and connected to the tractor cooling system. The 2 units that are used on E Premium are located on top of the transmission – well protected inside the tractor and near to the generator to keep the line routing distances short [3].

The control units are connected to the tractor CAN-bus. The operator input is done by a separate screen on the tractor display. The operator is able to activate the fan running in reverse direction as well as the activation of the external power.

5.9 Protective items

Using higher voltage on mobile machines creates the need for new safety concepts. It is necessary to protect the operator from getting in touch with higher voltage as well as protect the worker while assembling these machines. Also the service case has to be considered. Regulations that apply on stationary units have to be adapted to the special needs on mobile machines. On the E Premium tractors the output current on the inverter is monitored as well as the DC voltage link. Power management algorithms are applied to protect the system from overload. Given an overload situation the energy management is able to reduce the provided power to the electric drives/users. The electrical machines are equipped with temperature sensors in order to avoid over-heating.

5.10 Indirect features – flexible engine characteristics

The disconnection of engine auxiliaries from the diesel engine allows the optimization of the total available tractor power at the crankshaft. On an E Premium tractor this generates additional 7,5 kW made possible with intelligent power management. In addition to this it is also possible to offer higher power compared to the standard tractor already at lower diesel engine RPM. The fan drive – being independent from the diesel engine speed – is able to protect the diesel engine from overheating in this situation. It either allows operating the tractor at optimum fuel efficient conditions by lowering the engine speed in an ECO mode or increasing the power in order to be more productive. **Figure 8** shows that increased power compared to a non-electrified tractor already starts at 1250 RPM compared to 1700 RPM. Also the maximum possible power is higher compared to a non electrified tractor.

A DLG power mix test has shown that an E Premium tractor has more than 5% better fuel efficiency compared to the same tractor with a conventional electrical system.

6. Traction drives

Using electrical powered traction drives is possible and proven by concept studies for i.e. an electrical driven PTO but this area is still in an early stage of development.

The Belarus tractor prototype uses a diesel-electric concept as well as an electrical powered front PTO [8] (**Fig. 3**).

The MELA study [2] describes a continuous variable transmission with electric instead of hydraulic drives.

John Deere has shown a concept study with an infinite variable electrical driven PTO [9] (**Fig. 9**).

7. Energy Storage

Storing the energy has been an area that is mainly driven by new technologies of batteries. The automotive industry has the lead on this and developments that are done in this area could be adapted to agricultural needs when available.

Fuel cells have already reached the prototype stadium. CNH has presented a fuel cell powered tractor called NH2 on SIMA Fair 2009 [11].

8. Implement electrification

The application of electric drives on implements –power to be provided by the tractor - is the next step and already proven to be functional with the Rauch electrically actuated fertilizer spreader EDR [2] [7]. Main benefits for implements are obviously

- Enhanced controllability of power flow and therefore the reduction of input costs
- Optimized power distribution across implement structures
- Real plug & play for implements
- Enhancement to ISOBUS automation features

Similar to common architectures the tractor will represent the power source and - comparable to hydraulic drive systems - provide an adequate number of controlled power outputs. If particular implement designs incorporate an increased number of independently controlled drive systems, power electronics, the “control valves” of electric machines, will also be located on the implement. Mitigation scenarios will likely incorporate retrofit solutions to adapt latest electrically driven implements to existing tractors, given a potentially lower feature availability in comparison to tractor integrated power generation systems. The tractor and implement system electrification will be one of the biggest areas of research in the future. Agricultural System Engineering will apply technology to optimize processes and reduce input costs. Obvious system level benefits of electric drives will allow new types of machinery. For the Ag Industry a standardized interface is one key element for success. Mitigation scenarios have to be provided for existing equipment

For more detailed information a separate key note is available at the meeting [10].

9. Summary and Vision

Electric drives have entered the arena of agricultural machinery. Electrical driven tractor engine auxiliaries have already been introduced to a serial production tractor. Providing just the required power to auxiliary drives independent from the diesel engine speed increases the tractor efficiency or allows being more productive. Intelligent control of auxiliary drives helps to reduce fuel consumption.

First concepts and prototypes have been shown that have electrical traction drives on tractors. Other self-propelled machines have comparable needs in terms of drives and will likely follow in the future. The availability of electrical components meeting the design criteria for agricultural equipment is one key for success.

The tractor-implement system electrification represents the next mayor step towards future machine systems. Transfer of technology coming from automation industry and automotive applications is possible in regard of agricultural machines. Agricultural system engineering will apply electric drive technologies to optimize processes and reduce input costs. Obvious system level benefits of electric drives will allow designing new types of machinery. To make all this happen a standardized interface between the tractor and the implement is one key element for success. Mitigation scenarios have to be provided for existing equipment to allow creating critical mass of users. This will create acceptance for this new technology. The ideas for system-level opportunities in combination with automation, navigation and energy storage systems have to be developed.

This technology has the potential to become a new milestone in the history of agricultural equipment.

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FIGURES

Figure 1 - International Ellectral equipped tractor. *Source: [4]*



Figure 2 - Crankshaft mounted generator. *Source: [3]*



Figure 3 - Belarus 3023 at Agritechnica 2009. *Source: [8]*



Figure 4 - Electrical driven fan on E Premium tractors. *Source: [3]*



Figure 5 - A/C compressor on E Premium tractors. *Source: [3]*

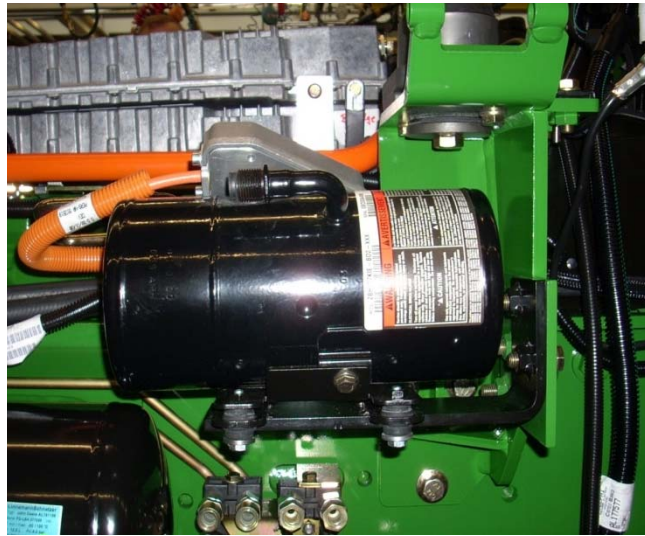


Figure 6 - External power outlets. *Source: [3]*

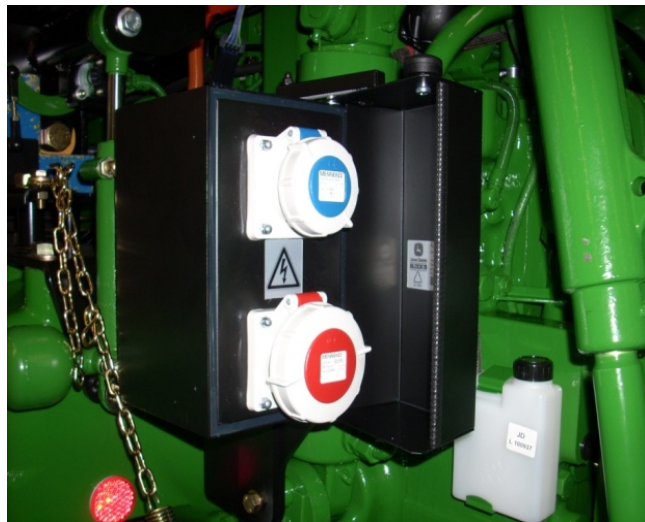


Figure 7 - Power units on E Premium tractors. *Source: [2]*

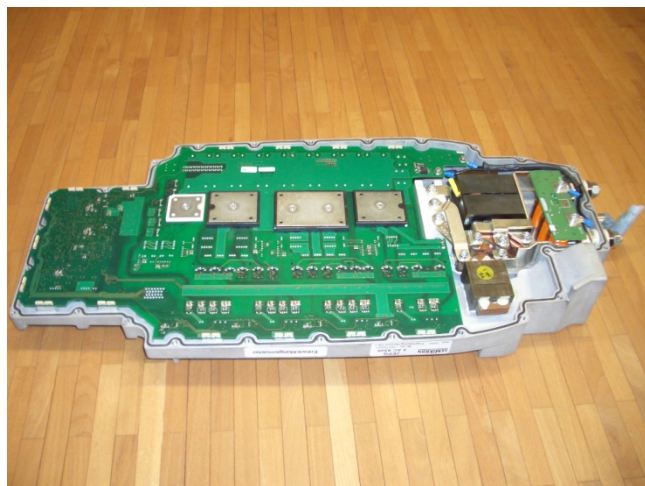


Figure 8 - Power curve E Premium with IPM. Source: [3]

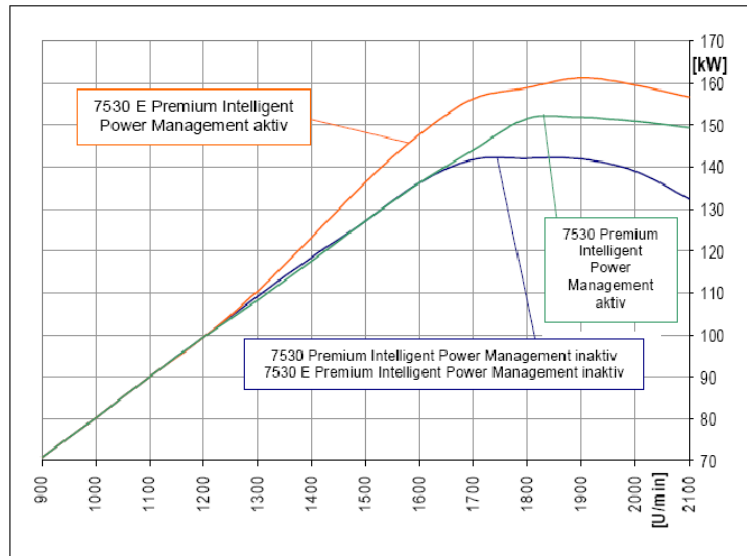


Figure 9 - E-PTO Concept. Source: [9]

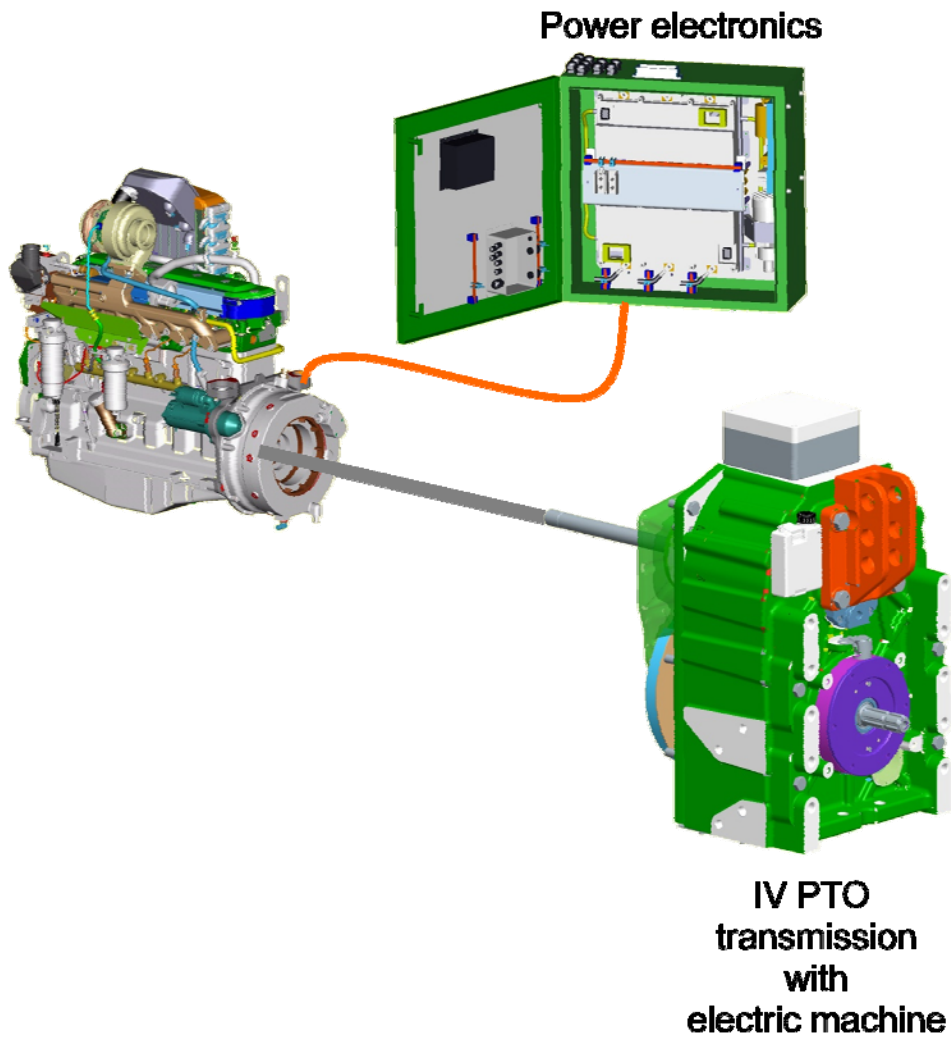


Figure 10 - ZF- terra+ transmission with generator. *Source: [6]*

