

High Voltage Electric Tractor-Implement Interface

Klaus Hahn

John Deere Werke Mannheim

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ABSTRACT

In the agricultural production process the tractor still has a vital role. It moves, carries, and powers agricultural implements that carry out the actual tasks like tilling, seeding etc. The tractor and implement therefore represent more of a system rather than two individual machines. The control of the increasingly large variety of functions calls for electronics. Current tractors transmit power mechanically and hydraulically. With the introduction of John Deere's E Premium series the first tractor with significant electric power became available. Such a tractor was modified to provide a controlled electric interface for implements to evaluate electric drives in this type of application. This paper presents the approach taken for the electrical interface, describes the ideas behind it, and will introduce some first results from simulation and prototype testing.

INTRODUCTION

THE BASE TRACTOR – At Agritechnica 2007 John Deere introduced the E Premium series of tractors which are equipped with a high-voltage onboard system. This series currently includes the Mannheim, Germany built 7430 and 7530 Premium tractors (*figure 1*). Due to their comparatively high power to weight ratio and compact size these tractors are often used by contractors and farmers who often utilize them for road transport on European roads. The onboard high voltage system of the E Premium is primarily used to power engine auxiliaries that were typically belt-driven in the past. *Table 1* gives an overview of the system's components while *figure 2* shows a schematic outline of the system. The table does not contain the additional inverter and other electrical components that are used to power a utility outlet which can be used to power electric tools and appliances up to 5 kW. As the tractor is introduced in Germany first, the outlet provides 230 / 400 V, 50 Hz and features wall type sockets at the tractor's back. For reasons of simplification, this outlet and the inverter driving it is also not shown in *figure 2*. Generally speaking though, the outlet could be configured to comply with a wide variety

of regional standard voltages and frequencies. This utility outlet may only be used while the tractor is not moving.



Figure 1: John Deere 7530 Premium Tractor

Table 1: HV Components on E Premium Tractors

Component	Approx. Power
Generator	20 kW
Fan drive	10 kW
A/C compressor	5kW
DC/DC converter	4 kW

In addition to the fan itself the fan motor also drives the air brake compressor that has a clutch enabling on-demand supply to the air reservoir. As with air pressure, the whole system is mainly about using only the power actually needed by the auxiliary drive and thereby cutting down parasitic losses of the diesel engine, eventually saving fuel. Additionally, the boost curve of the engine could be changed to provide more torque at even lower

engine speeds because appropriate cooling can be provided by the independently run fan.

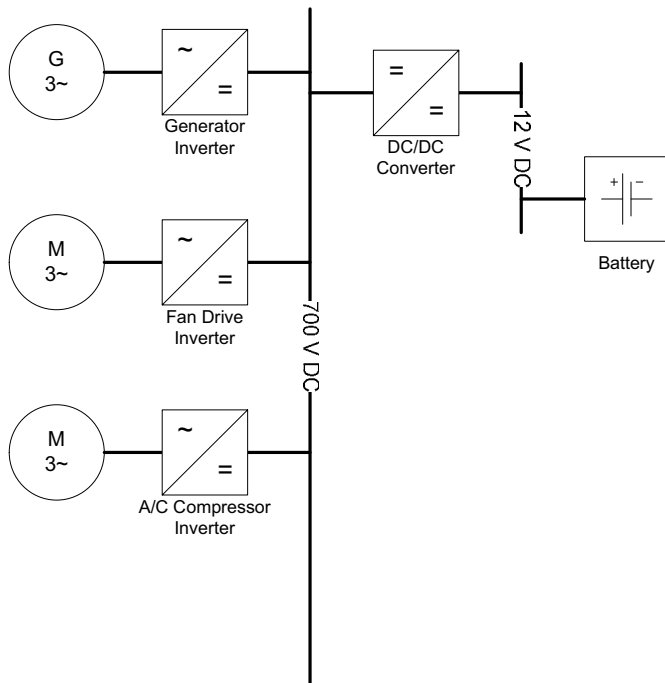


Figure 2: HV onboard system (simplified)

The AC induction flywheel generator (see *figure 3*) and the two motors in this system all run at voltages up to 480 V AC and are all 3-phase machines. The 700 V DC-bus connects the corresponding inverters and the DC/DC converter finally represents the gateway to the legacy 12 V DC system, effectively replacing the alternator to charge the battery and supply 12 V loads like working lights. The high power will avoid depletion of the battery especially during nighttime operations – sometimes an issue with conventional systems when loads draw too much energy.

ELECTRIC DRIVE FOR IMPLEMENTS – Electrically powered implements are currently not available due to the lack of tractors that provide enough electric power. The only electric interface to provide some power to implements is the ISOBUS connector but it is limited to roughly 1 kW [1]. Nevertheless, electric drives provide benefits in the field of control, and efficiency that make them a serious competition for traditional drive-lines. At the same time they face identical challenges PTOs and SCVs had to address in the past. These include:

- Power level
- Adjustment range (e.g. speed)
- Quality of control
- Coupling
- Standardization

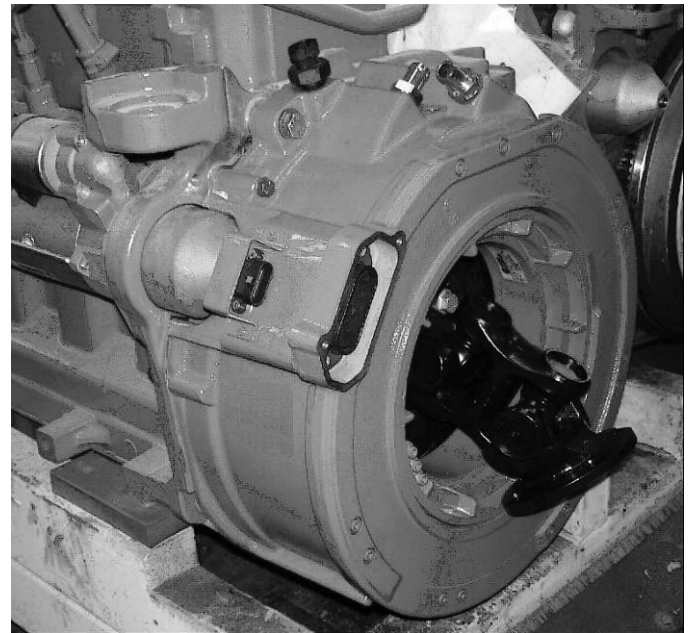


Figure 3: Flywheel Generator

It is necessary to state at this point that for the (expected) power level of drives found on agricultural machines DC-motors are not within the scope of research. 3-phase systems are expected to yield higher power density and efficiency in these applications.

According to TARASINSKI [2] the electrification of implements is the next logical step after utilizing electric drives for vehicle internal use. Yet, the specific reasons for using electric drives on implements are multiple. One major issue with implements is naturally coupling. Coupling in this context goes beyond the mechanical process of attaching the implement to the tractor but also includes the impact on design operator comfort and safety have. Of course, design also needs to make sure that drive-lines can be operated during turns and are not complicating folding mechanisms that are needed for transport. The high flexibility plus the independence from engine speed are the main benefits hydraulic drives offer for dealing with this issue. However, mechanical drives come with superior power density and higher efficiency; although this is sometimes reduced by unfavorably high engine speeds needed for a certain PTO speed. Against this background electric drives appear to overcome the downsides of the two other drives. In addition to that, they also require a reduced maintenance effort, do not leak, and behave independent of temperature over a wide range.

In reality however, the efficiency of a drive not necessarily leads to a productive solution. Especially in operations like seeding, fertilizing, and spraying, where usually the value of processed material surpasses that of the fuel used by far, and the potential impact on yield is tremendous, precision farming methods are on the rise [3]. With this comes an increasing need for control-loops that include tractor and implement. As these can't be closed by the operator any more, electronic systems like

ISOBUS are now being used to increase comfort and productivity, and enable precision farming [4].

The following table 2 gives an overview of different stages of technology on farming machinery and the main areas impacted. Note that efficiency is used in a more physical context whereas productivity has a more economical connotation.

Table 2: Technology Stages in Hard- and Software

		Area	
		Hardware	Software
Technology Stage	Enhanced Operation	Drive efficiency	Personal productivity
	Automated Operation	System efficiency	Tactical productivity
	Process Automation	Asset efficiency	Operational productivity

In this table, the obvious last element ‘strategic productivity’ stays in the farm management’s realm and reflects decision making for a farming methodology or planting of certain crops. It is therefore decoupled from this equipment focused approach – although buying equipment would definitely fall into this category. For the other stages it is not necessary to advance in both the hardware and software area simultaneously but it certainly boosts progress. However, the more advanced the stage is the more necessary a parallel progress seems to get.

An example for *drive efficiency* would be the reduction of power losses in a certain drive-train. The move from *personal productivity* in the form of e.g. headland management systems to *tactical productivity* is done by integrating tractor and implement functions into one control – as it is done with advanced ISOBUS implementation levels. *System efficiency* is achieved by integrating multiple sub-systems like engine, transmission and PTO into one overall control to operate at the optimum point of fuel consumption, for instance. Finally, in the *process automation* stage the focus is then on the coordination of multiple machines under changing conditions and priorities, the perfect example being a harvest operation adapting to an approaching thunderstorm. Electric drives can therefore be seen in more than one of these cells as both efficiency of the drive and the system may rise and at the same time superior controllability leads to gains in productivity. It is worth to note that communication – between operator and machine as well as between the sub-systems – is an element of increasing importance to all progress through this table.

MAIN SECTION

VEHICLE ARCHITECTURE – Like any other drive electric drives consist of mainly two elements: the control (i.e. the inverter) and the actuator (i.e. the motor). In the tractor context, the most imminent comparison is the hydraulic drive consisting of SCV and hydraulic motor. Added to this basic architecture may be a Power Beyond system directly coupling the implement’s hydraulics to the tractor’s hydraulic pump. In electrical terms this would translate to the implement’s electric drive being coupled to the tractor’s DC-bus – which is exactly what SZAJEK ET AL. proposed [5]. Although being the most flexible conceivable system, it puts a significant cost burden on each implement that now needs to have its own inverter. But because many implements sit in storage for most time of the year, this is an especially undesirable configuration. On the other hand, many implements make use of the tractor’s SCVs, however, automated functions almost always result into another valve block on the implement. For this reason, ISOBUS TECU class 3 will help to reduce hardware cost because e.g. the need for redundant valves goes away as the implement is granted control over the tractor’s SCVs. The same approach can be taken for the electric system by placing the inverters on the tractor. In addition to enabling multi-purpose use, this configuration also makes integration of the inverters into the tractor’s cooling circuit much easier. In fact, it could also function in a Power Beyond mode, using the inverters as safety switches to transmit DC. Hence, the proposed architecture for an E Premium tractor with an added implement drive looks like the one shown in figure 4.

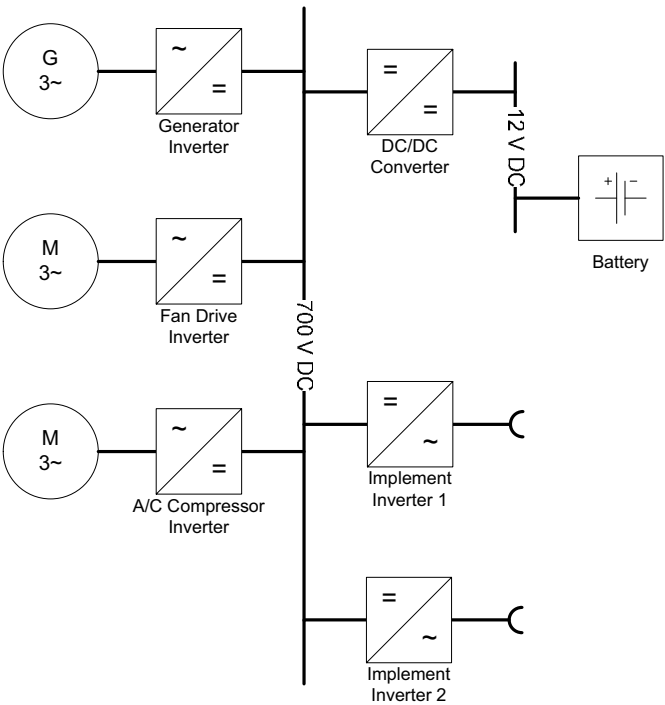


Figure 4: System w/ added implement inverters