Electricity for tractors and tractor-implement systems

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Abstract

Resulting from the background of increasing societal demands to mitigate climate change, drive trains of vehicles and mobile machinery need to be replaced by more efficient and alternative systems to reduce GHG emissions. Amongst other effects, this political enforced demand paves the way for electrification because electric machines provide greater efficiency, offer an outstanding level of controllability, have high levels of dynamic response behaviour, as well as have easily realizable independency of control of single drives, this is especially useful for highly precise, highly automated and even autonomous operation.

Electric drives offer the highest application power at maximum power density. While this is true for all the actuators, the problem of energy storage capacity and related costs will stay. There hardly is a business case for (fully) battery-electric agricultural machines except for smaller tractors, small robots, and turf machines. Even hybrid systems need a set of additional business cases or application benefits resulting from electrified drive systems. E.g., boost power or increased working speed in different conditions could be a driver for electrification. For battery systems, delivering service to the power grid could form a new (secondary) business cases in agriculture.

Electric drive systems in the long run, principally, could provide access to renewable (electric) energy to farmers, farmers are energy consumers while at the same time they are becoming more and more energy producers (mainly of electricity). Replacing fossil energy sources such as diesel on or near the farm, produced electric energy will be supporting the idea of short circular farming and could be an enabler for the introduction of electrified mobile machinery.

Already in today's realized systems, there are obvious benefits of the electric power supply ranging from tractors to implements. As a new power interface, tractors are providing electricity on different power and voltage levels, as well as at different frequencies for alternating current. Tractor-implement-electrification ("electric power off-boarding") is and will be the key driver for the implementation of electricity in tractors. The newly presented eAutoPowr transmission from John Deere is a power-split gear based on a combination of mechanical and electrical power transmission paths. It provides 100 kW electric power for off-boarding to operate electric implements and represents a milestone on the pathway towards electrification of agricultural machinery.

Historic background

Electrically driven agricultural machinery has a long history. The first solutions have been known since the

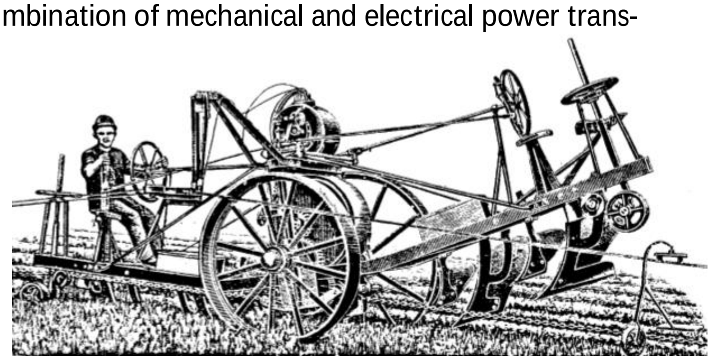


Figure 1: The Zimmermann plow (cable powered electric plow, 19th century)

19th century (Figure 1[1]). In the first half of the 20th century, emerging combustion engines displaced electric drive trains in mobile machinery almost completely. The outstanding advantage of combustion engines was the compactness of the engine and energy storage – the fuel tank provided energy for operating machines during a whole working day without needed a connection to stationary infrastructure for fuelling. This was a fundamental precondition for extended mechanization in arable farming.

The beginning of modern developments

New levels of battery technologies, as provided by Lithium-Ion-batteries, revived a global discussion about electromobility as well as other developments for electrification for mobility in general. Consequently, fifteen years ago the topic of electrification in agricultural machinery came into the foreground of technological discussions for the potential future design of mobile working machines. Gallmeier[2] references a project named MELA from STW GmbH, Agco, and the University of Applied Sciences Regensburg[3] started in 2001. The goal of MELA was to development an electro-mechanical power-split transmission for tractors with additional electric power supply for electric implements ("power off-boarding") through a 540 VDC connector. As in the MELA project, most activities for the electrification of agricultural machines have not focussed on using electricity as a primary energy source for driving mobile machines. Thus, only a very few hybrid drive train concepts, as well as all-electric mobile agricultural machines, have become visible to date.

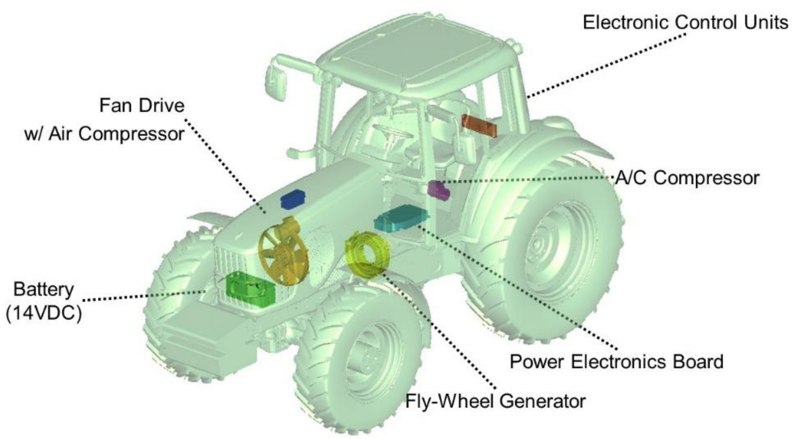


Figure 2: ePremium tractor concept 2007 (source: John Deere)

As Prankl et al.[4] in 2011 reported, in the following years many concepts for electric drive trains in agricultural machines were investigated as research projects. Prankl presented a concept for a PTO generator to provide electric power from conventional non-electrified tractors to implements.

In 2007, John Deere presented the 7530 ePremium serial tractor at the Agritechnica fair in Hanover (Figure 2). A 20 kW asynchronous crankshaft generator with a rectifier that provides power for several auxiliary drives (fan drive for engine cooling, A/C compressor, brake compressor). In this concept, the electric power was distributed via a 700 VDC-bus to the power

[1] Conservatoire National des Arts et des Métiers, „Bulletin de la société déncouragement pour l´Industrie nationale," 1897, page 670. Online available: http://cnum.cnam.fr/CGI/fpage.cgi?BSPI.96/684/120/1711/441/482

[2] Michael Gallmeier: Vergleichende Untersuchungen an hydraulischen und elektrischen Baugruppenantrieben für landwirtschaftliche Arbeitsmaschinen. PhD thesis Technische Universität München, 2009

[3] Michael Saller: Stufenlose Antriebstechnik, Presentation at Workshop MobilTron. Mannheim 2004. Referenced by Gallmeier[2]

[4] Prankl, Heinrich; Manfred Nadlinger; Florian Demmelmayr; Manfred Schrödl; Tino Colle; Gerald Kalteis: Multi-Functional PTO Generator for Mobile Electric Power Supply of Agricultural Machinery. AgEng Conference 2011, Hanover, VDI-Berichte Nr. 2124, 2011

consumers (electric machines with one inverter each). In total, power savings of up to 5 % were achieved. The inverters allowed control of fan speeds for engine cooling which consequently allowed for better engine characteristics and additional torque at low engine speeds.

Also at Agritechnica 2007, in cooperation with John Deere the company Rauch presented an electric fertilizer spreader powered through a modified John Deere ePremium tractor. In contrast to the MELA concept, power off-boarding to the implement was based on a prototype AC power interface with variable frequency. The fundamental idea was to have a limited number of implement inverters on the tractor to allow for multiple applications of cost intensive inverters. The operator or the controller device of the implement command the AC frequency to the inverters according to the required speeds of the spreader discs which are proportional to AC frequency. In this way, the functionality of the inverters is analog to the servo-control valves (SCV) in tractor hydraulics. The electrified system allows for the full functionality of a comparable conventional hydrostatic spreader but at about one third of power consumption for the operation of spreader discs.

As shown with the previous examples for the electrification of mobile agricultural machines, electric power off-boarding is one of the key drivers for electric developments. The two basic concepts for the transfer of high power (100 kW and more) were DC as in MELA and AC with variable frequency as shown by Rauch and John Deere 2007 with the electrified Axis EDR powered from a JD ePremium tractor. Both the AC and the DC concept merged in a standard created by the Agricultural Industry Electronics Foundation (AEF). In Agritechnica 2011, John Deere presented the 6210RE tractor - the successor model of the ePremium series. The 6210RE uses the same asynchronous generator as the ePremium tractors but electric power was used exclusively for off-boarding and no longer for auxiliary drives. As interface connector, the AEF power connector (generation 2.x) was used for the first time in a serial development.

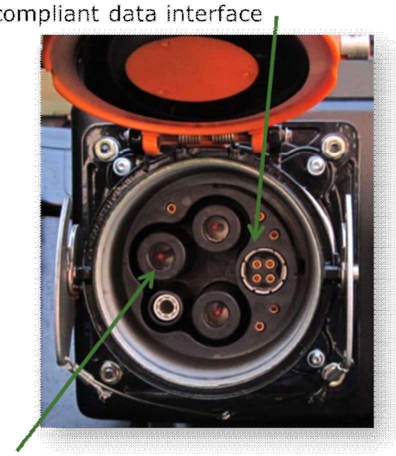


Figure 3: AEF connector generation 2.x (source John Deere)

The standardized AEF-connector for electric power transmission from the tractor to implement (as on the 6210R tractor) originally had an internal 4 wire physical Ethernet channel (Figure 3) to allow electric machines of implements to transfer the rotor position signal to an inverter on a tractor in a non-proprietary format. The actual information transmission was controlled in an industrial real-time system called EtherCAT. This way, implements could use highly efficient permanent magnet synchronous electric machines with unknown inverters on a tractor. This enabled more flexible and multiple uses for applications of the cost intensive power electronics (inverters). The newest AEF standard (generation 4.x) uses asynchronous 2-wire BroadR-Reach-technology.

Building on the AEF-connector having an embedded EtherCAT connector (AEF connector generation 2.x) for transmission of rotor position of electric machines on an implement, Peters et al.[5] proposed to use this EtherCAT connection for extended real-time data transmission for multiple sensor actor interactions, controller information exchange, and control tasks. In addition, the remaining bandwidth could be utilized for Internet Protocol as well as for tunneling ISOBUS. This proposal would have led to an integrated high bandwidth.

Efficiency

The primary motivation for the above-discussed systems and developments was to improve energy efficiency of drive trains which is an inherent characteristic of electric power components. Renius[6] gives efficiency levels for inverters close to 100 % at high rotation speeds (7000 rpm and higher), Figure 4, although with rather moderate values below 3000 rpm.

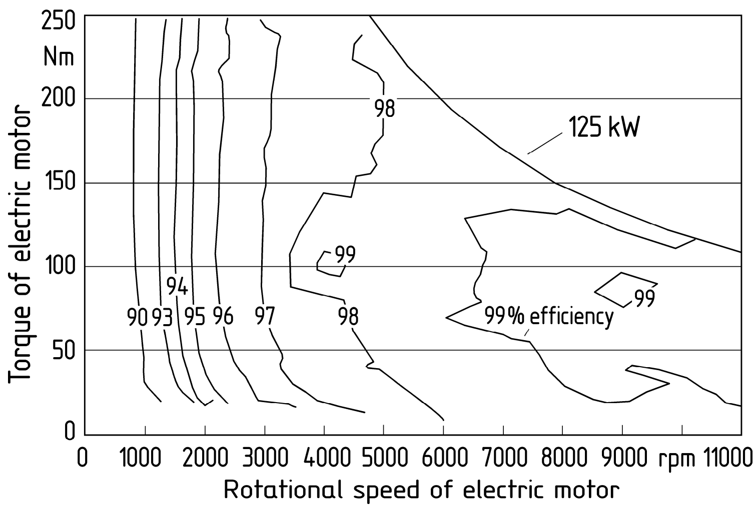


Figure 4: Efficiency of electric inverters[6]

Efficiency measurements of the company STW for a 140 kW combination of a converter and a permanent magnet synchronous machine (PMSM) resulted in a peak efficiency of 94% while a value of 92% counts for almost 70% of the efficiency map area[7]. This confirms that large electric PMSM motors can offer efficiencies of about 95% within a wide range of speed and torque.

Total efficiency of power electronics and electric machines over 90% can be reached with speed ratios from 1:2 to 1:3 at maximum. For drive trains in electromobility concepts, this makes necessary adjustable transmissions (e.g. shiftable gears) when full load at wider speed ranges shall be realized.

[5] Peters, Ole; Peter Pickel; Nicolai Tarasinski: Real time Ethernet for Tractor Implement Communication. 68. International Conference LAND.TECHNIK/Agricultural Engineering of VDI-MEG Agrartechnik and Society of European Agricultural Engineers (EurAgEng), Oct. 27th -28th 2010, Braunschweig, VDI Verlag Duesseldorf, 2010, ISBN 978-3-18-092111-2, pages 285 - 292

[6] Diagram courtesy of Karl Th. Renius, based on material of Chang et al, Institute of Automotive Technology, TU Munich

[7] Renius, Karl Th.: Fundamentals of Tractor Design. First edition. Springer-Verlag, Cham/Switzerland: 2019

Excellent controllability as key enabler for precision farming

The approach of improving efficiency has not yet been enough to force a breakthrough in electrification for mobile agricultural machines. However, with emerging precision or smart farming systems, it is becoming evident that a new drive train and actuator technology is needed to provide highly dynamical response behavior to enable high speed and high precision operation of machines, which cannot be achieved with conventional hydrostatic or mechanic components. For this, electrification will likely be the key enabling technology. Besides the good controllability, electric drives allow for easy configuration and operation of independent actuators. The John Deere ExactEmerge system is exemplarily proof of this thesis. ExactEmerge is a multi-row planter that places seeds of row crops (corn, sugar beet) with an accuracy of about ±1 cm at operating speeds close to 20 km/h (see Figure 5). To achieve high speed operation while simultaneously providing outstanding accuracy, two electric servo motors are needed in each seeding unit – one for seed singulation and the other for acceleration of seeds up to their respective row so that the speed direction is opposite to the movement direction of the tractor, insuring a relative speed over the ground of exactly zero. The independent control of all seeding units allows for the creation of complex patterns or, as shown Figure 5, different curve radii. A comparable functionality based on mechanical or hydrostatic actuators is not possible.

Figure 5: Single seed planter ExactEmerge with 8 rows (picture: John Deere)

For the electric power supply, John Deere proposes either using the AEF interface or a low voltage 48 VDC system. Because the single corn seeders only need low power, 48 VDC will be sufficient. 48 VDC power off-boarding requires minimal safety related measures and is therefore cost effective but limited in power level. Two new electric power and voltage levels for interfacing will likely be established in the future:

- 48 VDC for low power applications
- AEF connector for high power applications up to 150 kW per connection

Upcoming 48 VDC technologies also have potential for tractor (or other machines) onboard applications and hybridization (e.g. with electric turbochargers and small size batteries) and thus might help to overcome the limitations resulting from today's 12 VDC vehicle systems.

As a consequence of exactly controlled seeding with ExactEmerge, it is now possible to apply mechanical hoes. Accurate seed placing allows for the creation of respective tracks in the cross direction of the seed row enabling cross weeding. Herbicide application can be reduced significantly with this advancement.

An alternative approach under broad discussion today is the application of small field robots such as the Xaver robot for seeding presented by Fendt / Agco on Agritechnica 2017 or several other small field robots used in plant protection measures. These small field robots also represent a high level of automation and even autonomy achievable only with electric actuators.

Electromobility in agriculture – access to renewable energy
Another reason for the electrification of agricultural mobile machinery is electromobility. The production, supply, and consumption of sustainably generated energy from renewable resources has great potential for being a key pillar in creating higher added value in land cultivation and forestry. In principal, rural production systems contain the most important operational resource in the production of renewable energy: land – e.g. land to grow energy plants as primary commodities for (energy) biorefining, land to install wind power plants, as well as surface areas for installation of photovoltaic systems. Thus, farms will transition into the role of energy producers with most energy being electric.

On the other hand, agriculture and forestry are inherently depend on energy consumption. Because costs for energy from fossil sources (e.g. fuel) are increasing, farmers and similar SMEs will strive to establish their independent energy production lines to substitute for fossil energy sources. Because short circuits provide the highest energy efficiency, decentralized energy production in rural areas and the consumption of that energy should be spatially integrated. This also eases demand on infrastructure for energy distribution and supply. In this way, decentralized rural energy supply and consumption concepts may have great indirect benefits on the development of energy supplies in urban areas and may contribute to the future bioeconomy in total.

In several governmentally funded projects, JD developed functional prototypes for hybrid and grid-plug-in hybrid vehicles. 2011, Schrank[8] presented a concept for hybrid tractors based on modified ePremium and 6210RE tractors. The main aspects of these concepts were standard hybrid features and power off-boarding for hybridization.

[8] Schrank, Claudia; Peter Pickel; Rainer Gugel; Barbara Böhm; Nicolai Tarasinski: Electro-Mobility in Agriculture – A Contribution Towards a Safe and Sustainable Energy Supply. Paper. 69. International Conference LAND.TECHNIK/Agricultural Engineering of VDI-MEG Agrartechnik and Society of European Agricultural Engineers (EurAgEng), Nov. 11.-12. 2011, Hannover, VDI-Berichte 2124, VDI Verlag Duesseldorf, 2011, ISBN 978-3-18-092124-2, pages 231-237

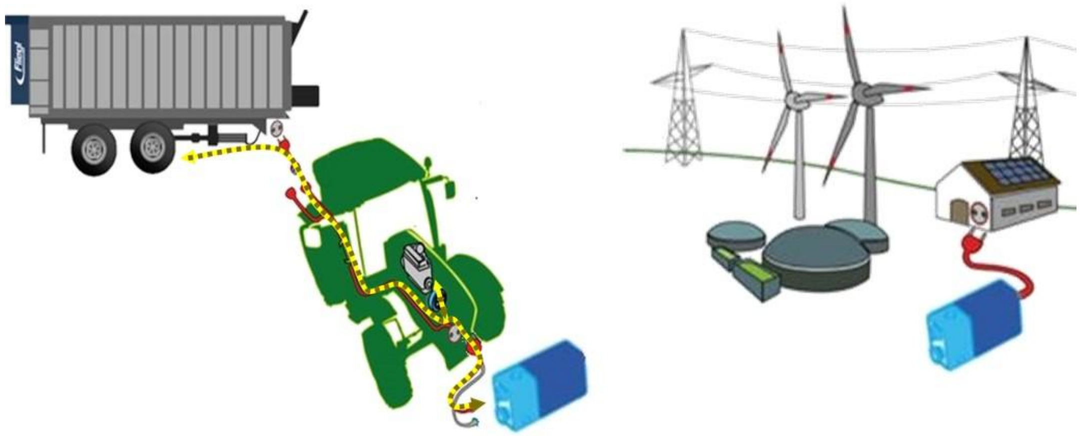


Figure 6: BatteryBoost idea (John Deere)

The latter idea was further developed. In 2015, the BatteryBoost system – a 6210RE with an external battery – was shown at the SIMA fair in Paris (concept shown in Figure 6). The key component is the John Deere BatteryBoost tractor (based on a 6RE model) equipped with multiple high-power interfaces according to AEF-standard and an electric backbone for bi-directional energy flow to and from the implements. The main innovation is an attachable battery onto the front hitch. Off vehicle, the battery can be used as a grid plug-in buffer to support the supply and production of renewable electric energy (internally on the farm). In addition, John Deere's concept also includes a vision of using batteries and/or battery pools for external services into the power grid.

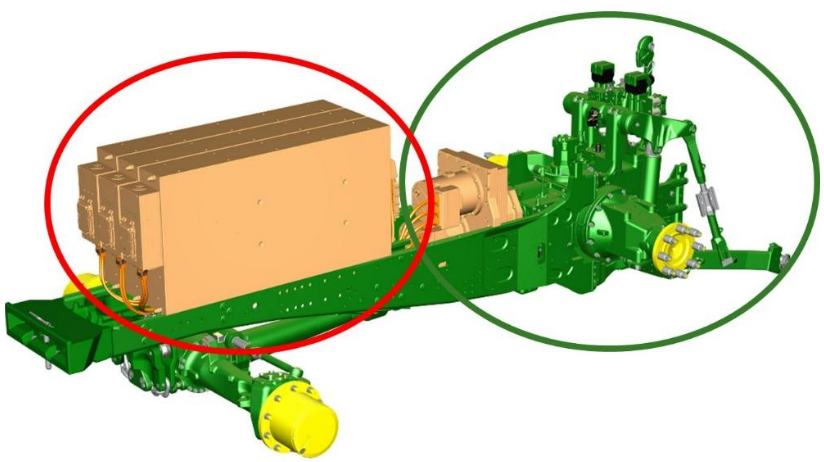


Figure 7: Sketch of exhibit of SESAM tractor as shown on SIMA fair (Paris, 2017, John Deere)

When the battery is attached to a tractor, the tractor is converted from a conventional tractor into a "grid plug-in hybrid tractor" with a battery change system. Simultaneously, as the battery replaces the counter ballast of the tractor, it can also be used as a range extender or used to boost either the drive train or an electric implement via passing the tractor power train. Thus, the power from the effective tractor implement system can be about 60% higher as the rated tractor power.

The dual use of the battery, use as a mobile battery on ag machines and use as a stationary grid buffering battery, significant additional value is created. With the application of batteries for farm internal and external power-grid-services, the operational time of the battery can be increased by up to 100% and depreciation can be financially more effective. Moreover, once aging warrants the battery no longer suitable for mobile use, the stationary use of the battery gives it a second life.

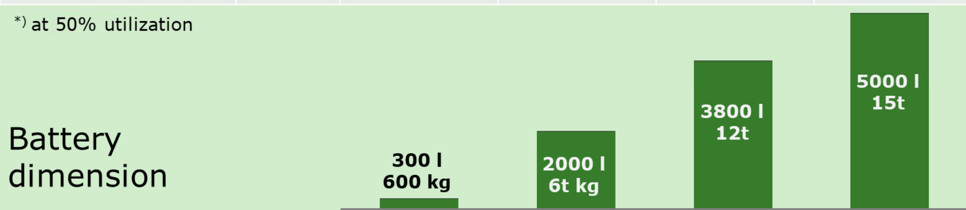
In an ongoing publicly funded project called Designetz[9], the idea of the provisioning of grid-services through batteries in agricultural machines is being further investigated with regards to predictive battery and energy management and control.

All battery electric tractors

A first fully operation all battery-electric tractor was the SESAM tractor. The SESAM tractor has a peak power of almost 400 PS through two electric machines – one for the drive train and the second for PTO and auxiliaries (golden illustrated parts in green oval). The Lithium-Ion-battery (red oval) has an energy capacity of 130 kWh. Thus, the rated power of the system at 1 C discharge current is 130 kW, showing a fundamental shortfall of the smaller then required energy content. At the rated power, recharging of the battery would be necessary in less than 1 h of operation. Thus, the battery dimensions pose an inherent problem for all electric tractors. See Figure 6 for an explanation of this fundamental tractor battery problem. For large tractors, long periods of continuous operation required by customers leads to enormous battery geometry and weight. As an example: at a desired power utilization of 50 % of the rated vehicle power, at a continuous operation time of 12h, and a rated vehicle power of 290 kW, the battery would need to weight 12t and be 5 m³ in volume. However, battery dimensions seem to be realistic for smaller tractors.

Rated power	kW	50	180	290	380
Time of operation	h	4	10	12	12
Battery capacity*)	kWh	100	900	1740	2280

*) at 50% utilization



Assumptions:
~6,6 kg/kWh (for comparison SESAM tractor at ~10 kg/kWh)
~2,2 l/kWh

Figure 8: The inherent dimension problem of tractor batteries (source: Fendt / Agco – modified by author)

A 50 kW tractor (80 hp), as shown in Figure 9, could operate with a 600 kg battery providing an energy capacity of 100 kWh.

Such a tractor theoretically would need to be recharged after 4 h of operation at 50% utilization. Due to the constraint of never deeply discharging a batter the net or effective time of continuous operation is about 20% shorter than declared. Additionally, aging limits operation range.

[9] Consortium project Designetz, „Schaufenster-Projekt“ of the German Ministry for Economics and Energy (BMWi), Sub-Project SESAM-Farm, Project-Id.: FKZ 03SIN217, 2018-2020. Project lead Innogy, sub-project-lead John Deere

Figure 9: battery electric tractor Fendt e100 Vario [left] and basic feature concept [right: 1 - high-performance battery: 700 V, 100 kWh Li-Ion; 2 - DC quick charging and 400 V standard charging; 3 - efficient electric motor with high power density; 4 - dynamic power management; 5 – power supply for implements; 6 - innovative thermal management with heat pump] (source: Fendt / Agco at Agritechnica 2017, Hanover)

Increasing power density through electrification

As demonstrated above, weight and volume limit the applicability of batteries being permanently installed on agricultural machines. In Figure 7, (green oval) two electric machines are connected to a standard tractor transmission, which itself is connected to a tractor rear axle. This combination of electric machines, transmission, and axle covers the complete functionality of standard tractors (drive, hydrostatics, PTO, three-point hitch) in a highly compact form with low weight.

The SESAM tractor is set up in the frame and shape of a standard tractor providing about 200 hp. Not considering the battery, the SESAM tractor would be able to deliver 400 hp permanently. It is attractive to apply electrification to agricultural machines with the goal of increasing performance (or power) and the power density. The principles of energy transfer from stationary infrastructure to mobile machines needs renovation. One possibility is to apply battery quick change concepts (as investigated by Kegel[10]).

One alternative approach developed by John Deere is the GridCON project[11]. Inspired by historic solutions, mining machines, and slurry distribution via hoses, John Deere developed a prototype concept for a fully electric, cable powered, in-field autonomously operational machine, the GridCON (Figure 10). The GridCON tractor is a visionary functional prototype that is powered via a 2.5 kV (AC, 3.6 kHz) cable connection from the field border to the machine, allowing for 300 kW permanent power transfer (can be enlarged). The cable drum carried by the machine has a 1000 m range (cable length, extendable). Onboard, GridCON is using a 700 VDC bus for electric power distribution, implements ("electric power off-boarding" with cooling infrastructure provided by the GridCON tractor) can then use this electric power.

For special maneuvers (e.g. for going to field border when starting work) a tractor "driver" can

[10] Kegel; Volker: Batterieelektrischer Traktor. PhD thesis Technical University Berlin, PhD defense in 2017, published by Shaker, 2018, ISBN-10: 3844056823, ISBN-13: 978-3844056822

[11] Project: Grid-Connected Agricultural Machine (GridCON), John Deere GmbH & Co. KG et al., funded by German Ministry for Economics and Energy (FKZ: 01ME14004A et al.), project agency DLR (Deutsches Zentrum für Luft- und Raumfahrt – German Aerospace Center), 2015-2018

manage the machine with remote control. At in-field operation, the vehicle follows fully autonomously pre-planned paths with operational speed of up to 20 km/h. In fieldwork, the cable in both modes (unwinding and winding up) is guided by a robot arm keeping the cable friction-free and at low load.

Figure 10: The GridCON tractor (source: John Deere)

The central onboard industrial automation system changes the GRIDON vehicle into a machine tool on wheels: the automation system controls all actuators on the vehicle in real-time (cycle time 1 ms) using the industrial real-time communication system EtherCAT.

The GRIDCON tractor uses very similar electric drive technology as its predecessor (SESAM tractor). 100 kW of power is applied to the drive train. 200 kW are used for power off-boarding to implements. The efficiency of the power transmission from the grid connection point to the tractor internal 700 VDC-bus is about 85 % on average with a maximum of almost 90 % at about 80 kW[12]. At higher power, a near linear decrease of efficiency is observed, mainly due to ohmic losses on the cable. According to results from the SESAM tractor project[13] this characteristic would also apply for a battery that achieves an energy efficiency from the grid and discharges it to the internal DC-bus at 1C of 90 %, falling linearly with increasing C-rates for discharging.

[12] Tarasinski, Nicolai; Volker Kegel, Julian Daubermann: GridCON - Development and Testing of a Cable-fed Full Electric and Autonomous Agricultural Machine. In. VDI-Berichte 2332, S. 339-344. Düsseldorf: VDI-Verlag 2018, ISBN:978-3-18-092332-1

[13] Project: Entwicklung eines vollelektrifizierten Traktors (SESAM), John Deere GmbH & Co. et al., funded by German Ministry for Economics and Energy (FKZ: 01ME12122A et al.), project agency DLR (Deutsches Zentrum für Luft- und Raumfahrt – German Aerospace Center), 2013-2015

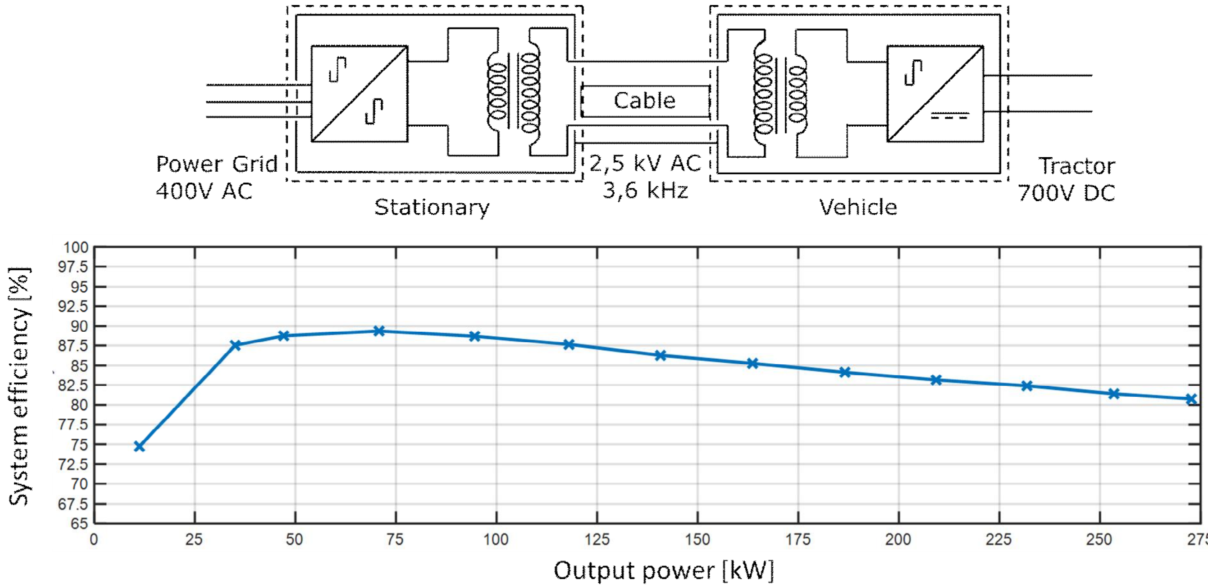


Figure 11: GridCON powering concept and system efficiency (source: Tarasinski)

The total weight of the functional prototype GridCON is about 8.5 t (empty, but including cable drum and robot arm), this is a similar weight to the base vehicle (a 6195R conventional John Deere tractor) but the GridCON has double the power and is emission (exhaust gas and noise) free. In a series design, further weight reduction could be achievable.

At Agritechnica 2019 and the VDI AgEng conference Pfaffmann et al.[14] John Deere presented a further developed prototypic concept (Figure 12) based on GridCON resulting from the project Feldschwarm® [15].

Figure 12: Field swarm unit (source: Pfaffmann et al., John Deere)

One key element of this concept is to split the tractor functionality and the cable drum. This allows the attachment of more than one swarm units to one cable guiding vehicle. Forming a controlled ("platooning") swarm. With this, further cost and weight reductions (compared to GridCON) with increased power density could be achieved.

[14] Pfaffmann, Simon; Nicolai Tarasinski; Felipe de Moraes Boos: Swarm Unit – Development of a Fully Electric Agricultural Machine with External Power Supply. To be publish as VDI-Berichte No. tbd, pages tbd, Düsseldorf: VDI-Verlag 2019, ISBN: tbd

[15] Wachstumskern Feldschwarm® - Verbundprojekte 2 and 4. John Deere GmbH & Co. KG et al., funded by German Ministry for Education and Science (FKZ: 03WKCW2E et al.), project agency PTJ (Projektträger Jülich), 2017-2020

The system shown in Figure 12 uses a newly designed and dedicated implement-connection that allows steering of an articulated vehicle.

Summary and additions

There are four top arguments for electrification of agricultural machinery

- Efficiency
- Controllability
- Access to renewable energy
- Power density

According to these arguments or aspects, electrification will be a key enabling technology for future precise and highly sustainable farming. Additional arguments not covered in this report but also supporting the need for more electric drive trains are:

- Elimination of toxic emissions (such as soot or NO_x)
- Significant reduction of noise emissions
- Elimination or reduction of oil and grease leakages
- Minimized maintenance or maintenance free drives

Future discussions and developments must also deal with problematic aspects of electrification such as safety topics on high voltage systems and mandatory new education profiles of workshop staff. Finally, costs and business models will ultimately decide the future of electric drives.

Another important side aspect of electrification is information and communication technology. As electrification is a key technology in enabling highly precise operations in farming, the development of electrified systems goes hand in hand with the development of smart and digital farming.

At Agritechnica 2019 John Deere presented a new tractor transmission: the eAutoPowr which has a structural architecture comparable to a dual-path transmission with two electric machines on the two main shafts. The basic idea of the eAutoPowr is the same as of the classic hydrostatic-mechanical power split transmissions, it combines the functionality of a variable transmission with the efficiency of a standard mechanical gear. Because eAutoPowr does not use hydrostatics for power transfer it claims to have better efficiency over other power split transmissions.

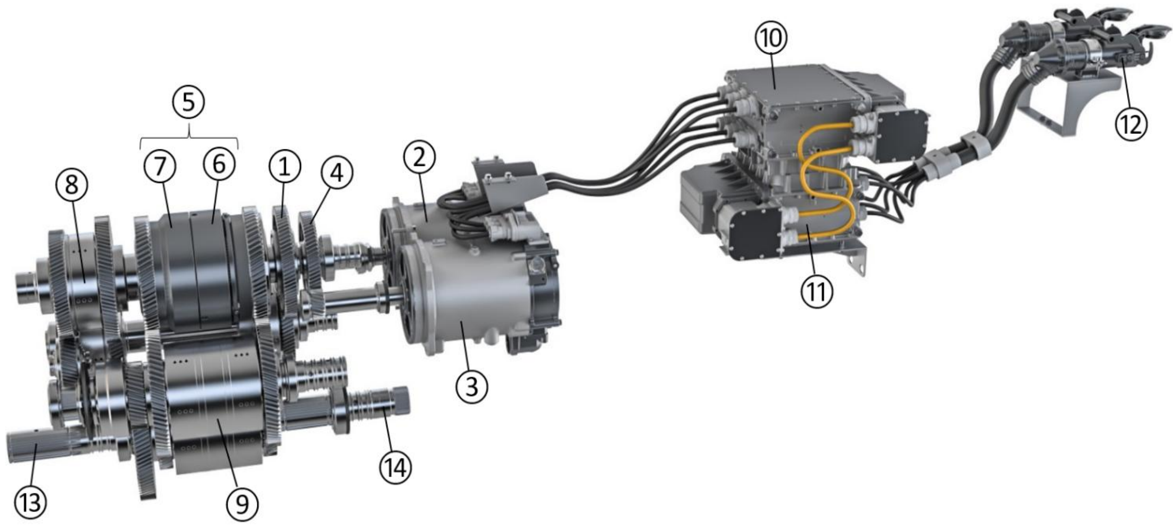


Figure 13: New eAutoPowr transmission of John Deere (① drive through and gear stage from diesel engine to MG1, ② first electric machine (MG1), ③ second electric machine (MG2), ④ gear stage from MG2 to double planetary gear, ⑤ double planetary gear, ⑥ "LO" planetary gear with sun and ring drive, ⑦ "HI" planetary gear with carrier and sun drive, ⑧ reversing circuit, ⑨ switching group module, ⑩ double inverter for MG1 and MG2, ⑪ double inverter for external attachments, ⑫ AEF-interfaces for coupling external attachments, ⑬ mechanical output front axle differential, ⑭ mechanical output Rear axle differential)

In addition, the electric machines allow for power off-boarding to implements via 2 AEF-connectors (generation 4.x) for up to 100 kW. The 8R series tractors with eAutoPowr and the AEF high power connector will go into serial production for the first time. In addition, the low power 48 VDC interface will continue to be refined in the coming years.