Tractor/Implement Electrification:

Opportunities and Challenges

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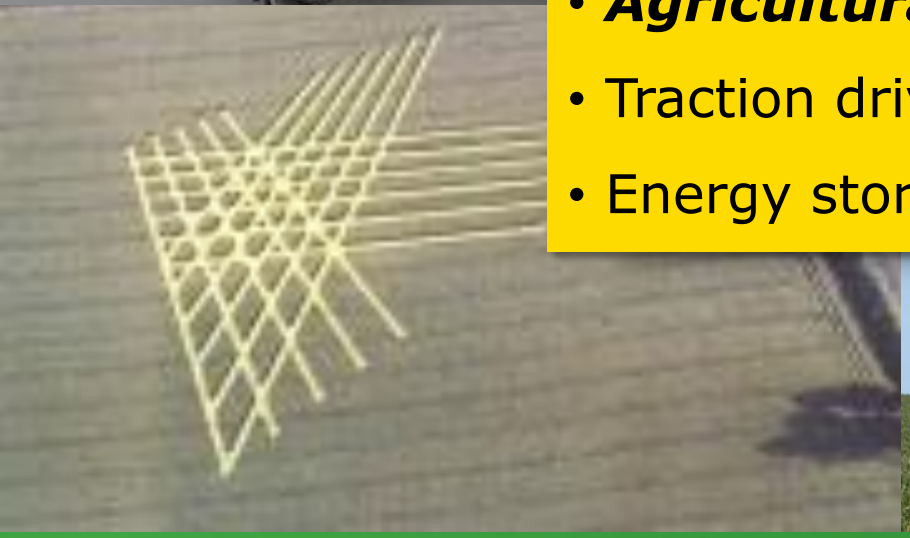
Electric Drives: Hype or sustainable trend?

Key areas of application

- Engine auxiliaries
- ***Agricultural implements***
- Traction drives
- Energy storage



Sources:
KvernelandRauch,
Amazonen Werke,
ZF

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Tractor/Implement-Electrification

Tractor & Implement: One System

Customer Value Added: Productivity & Automation (TIM)

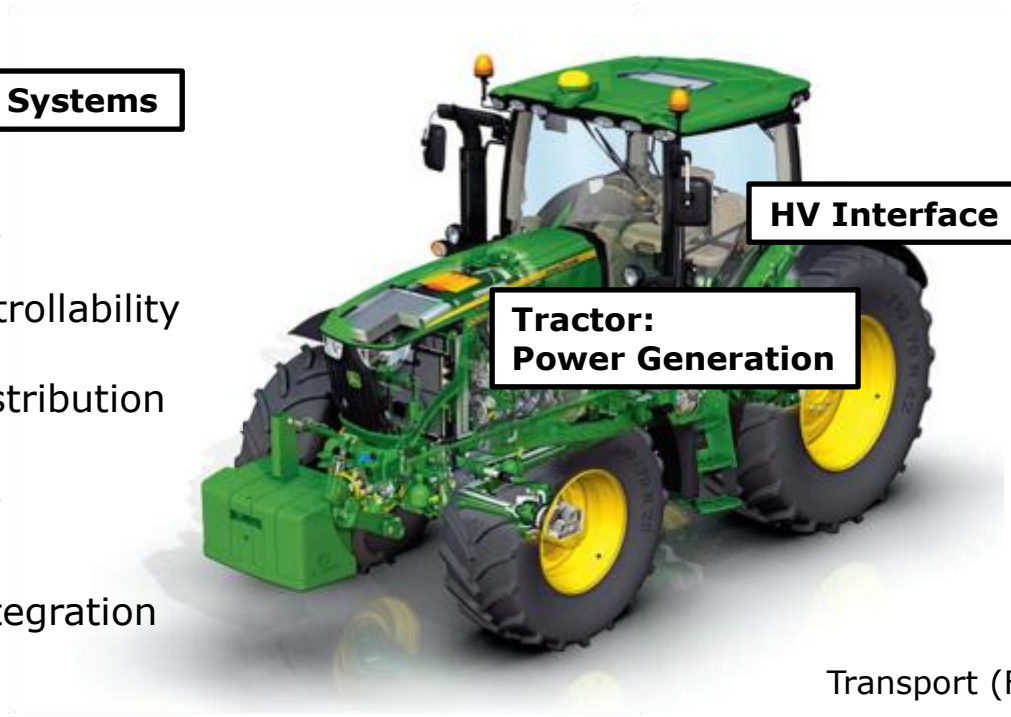
Customer Value Chain

Electric Drive Systems

Excellent Controllability

Improved Distribution

Optimum Integration



HV Interface

Fertilizing (Rauch)

Green Land (Poettinger)

Transport (Fliegl)

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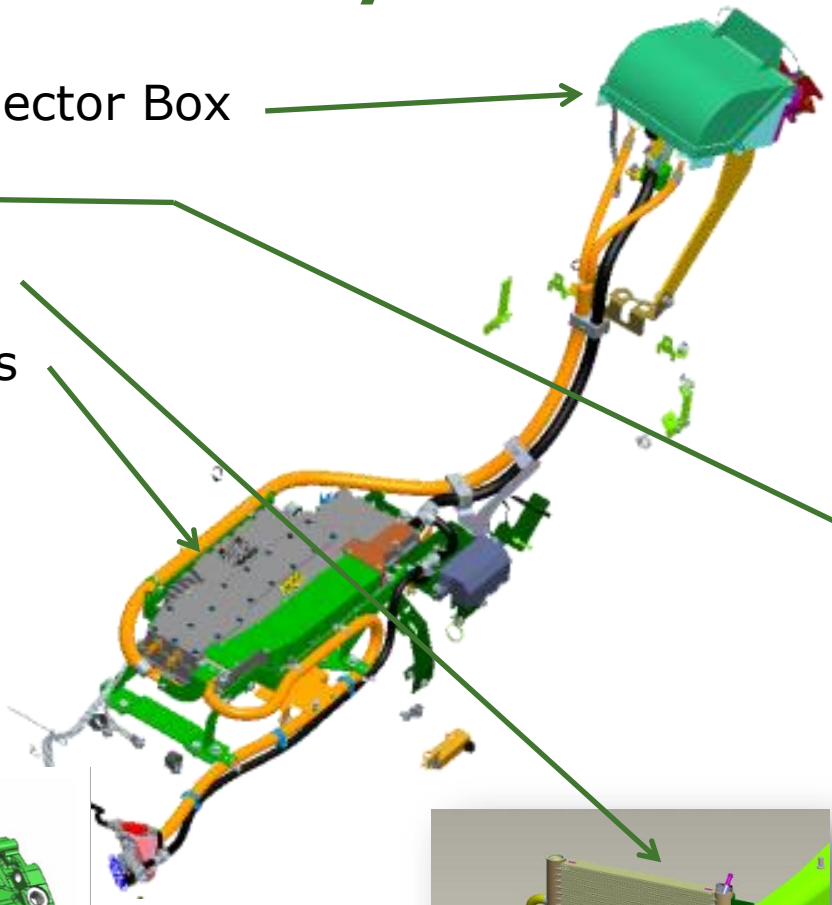
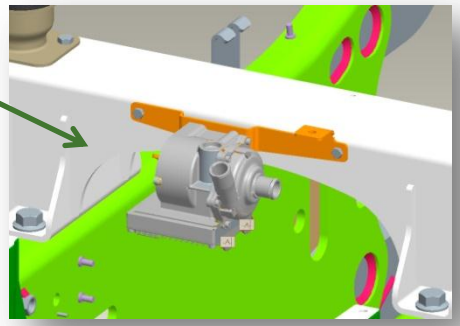
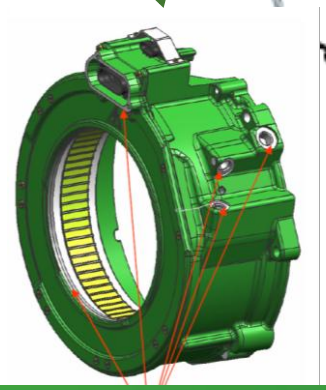
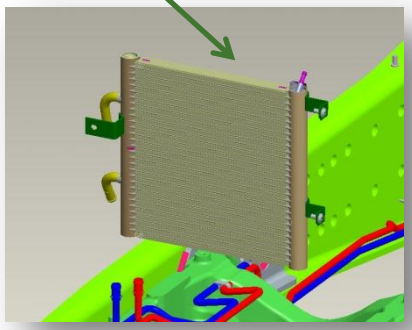
John Deere 6210RE: System and Components

- Implement Connector Box
- Coolant pump
- Heat exchanger
- Power electronics
- Generator









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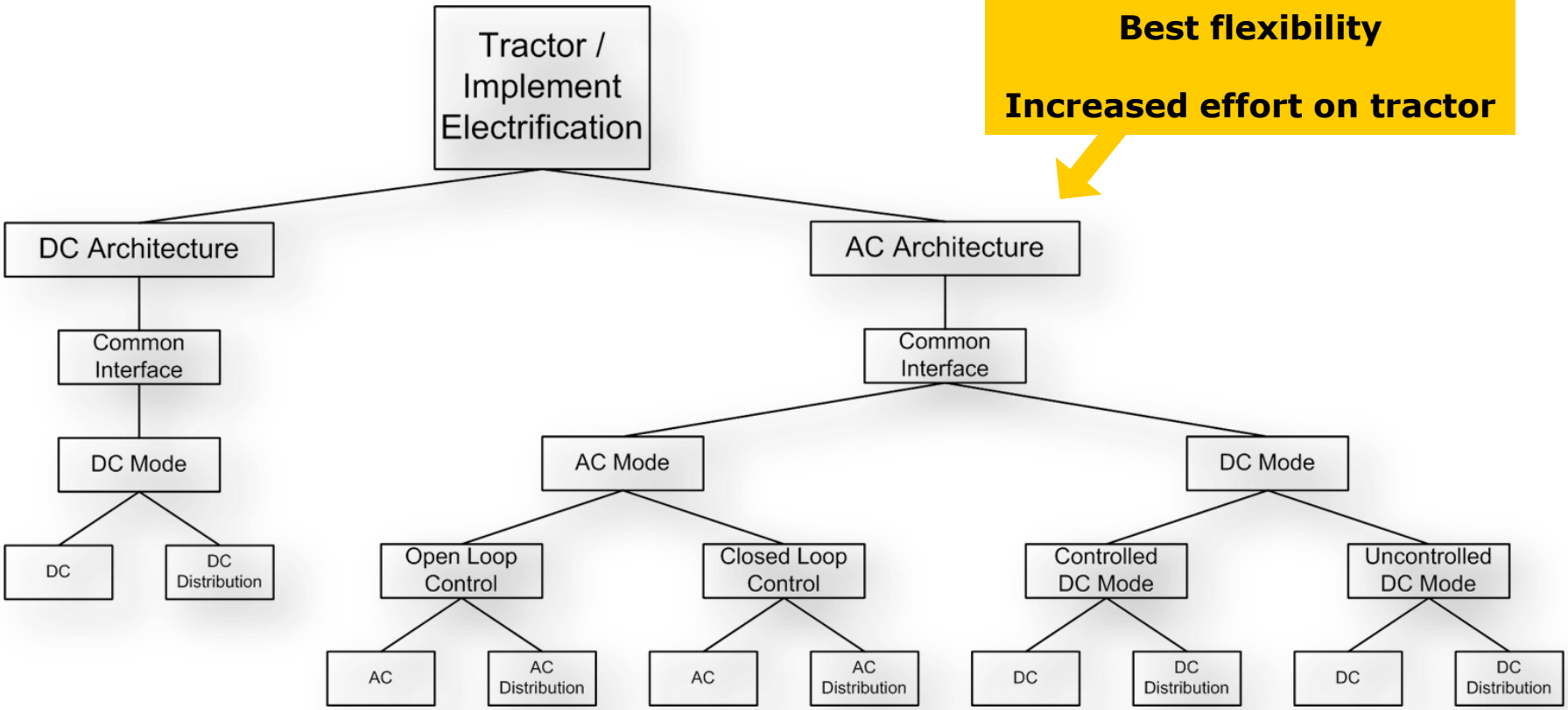
Tractor/Implement Electrification: Configurations

JD 6210RE

Best flexibility

Increased effort on tractor



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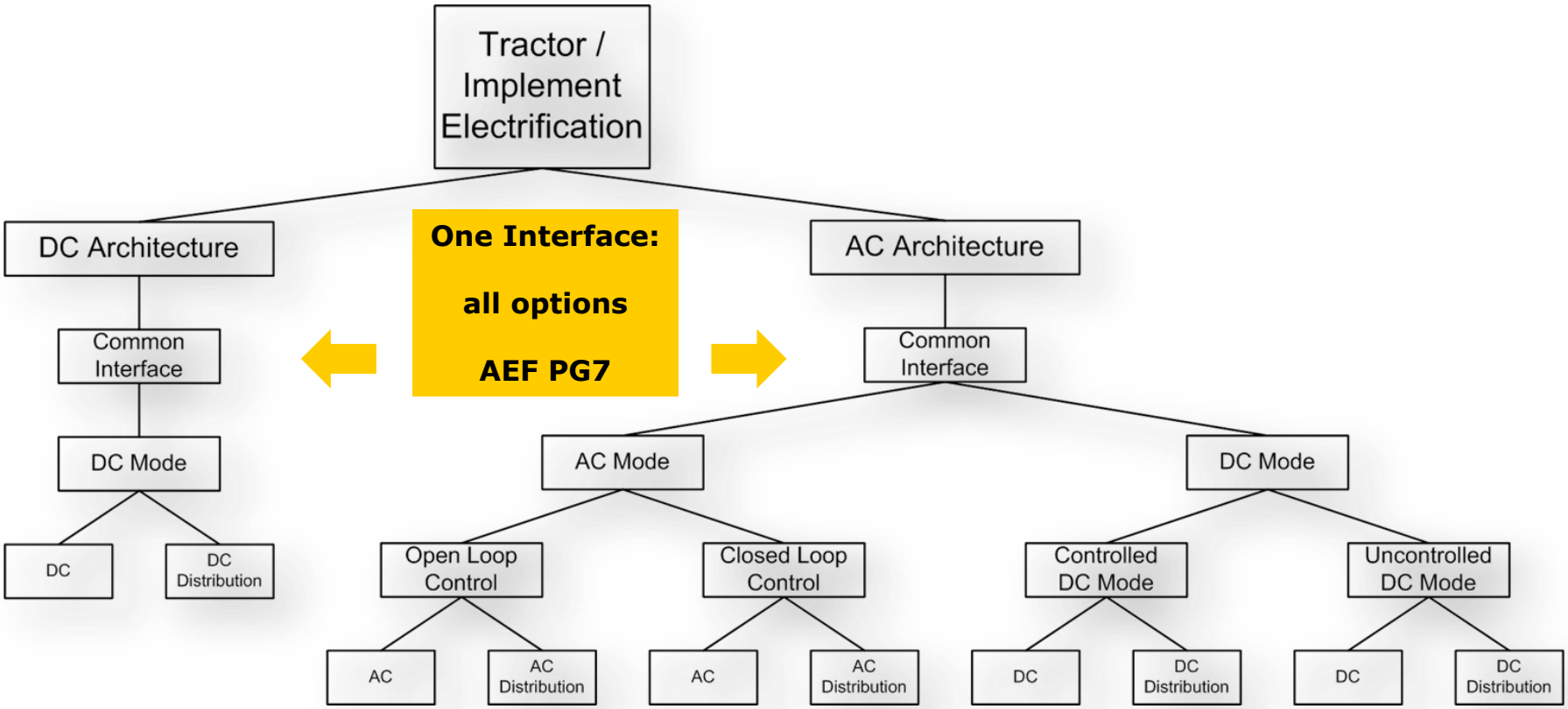
Tractor/Implement Electrification: Configurations



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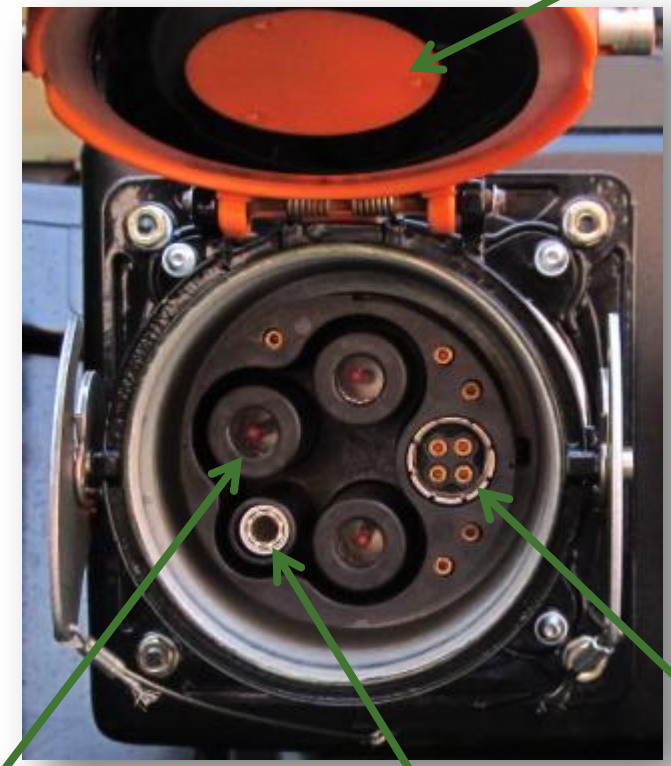
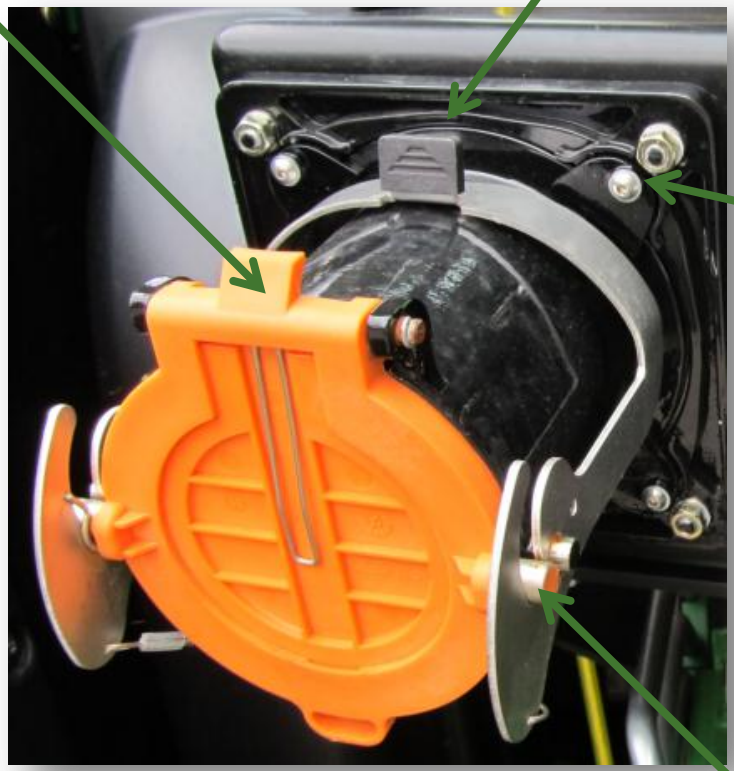
Physical HV Power Interface (ref. AEF PG7)





GEN2: lid top mounted

Connector handle

Break away feature

Power contacts DC / AC

Leading contact for EPBC

Real time Ethernet compliant data interface

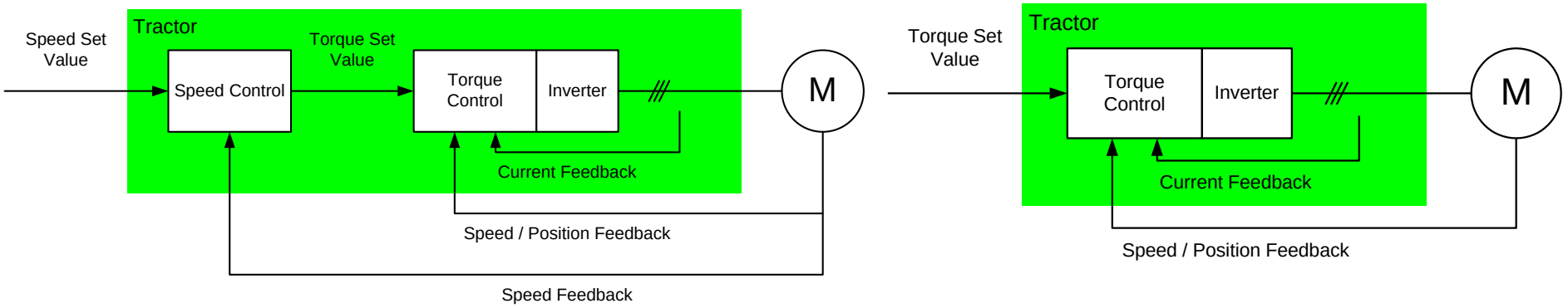
Metal bushing on plastic cover

Operation Modes

2 independently controllable interfaces

- PMSM control (closed loop)
  - Speed control
  - Torque control

- Further modes (6210RE optional)
  - AC-induction machine control (closed loop & open loop)
  - DC (implement located power electronics)
  - UPS, e.g. 230V/400V @ 50Hz (+ stationary hardware)



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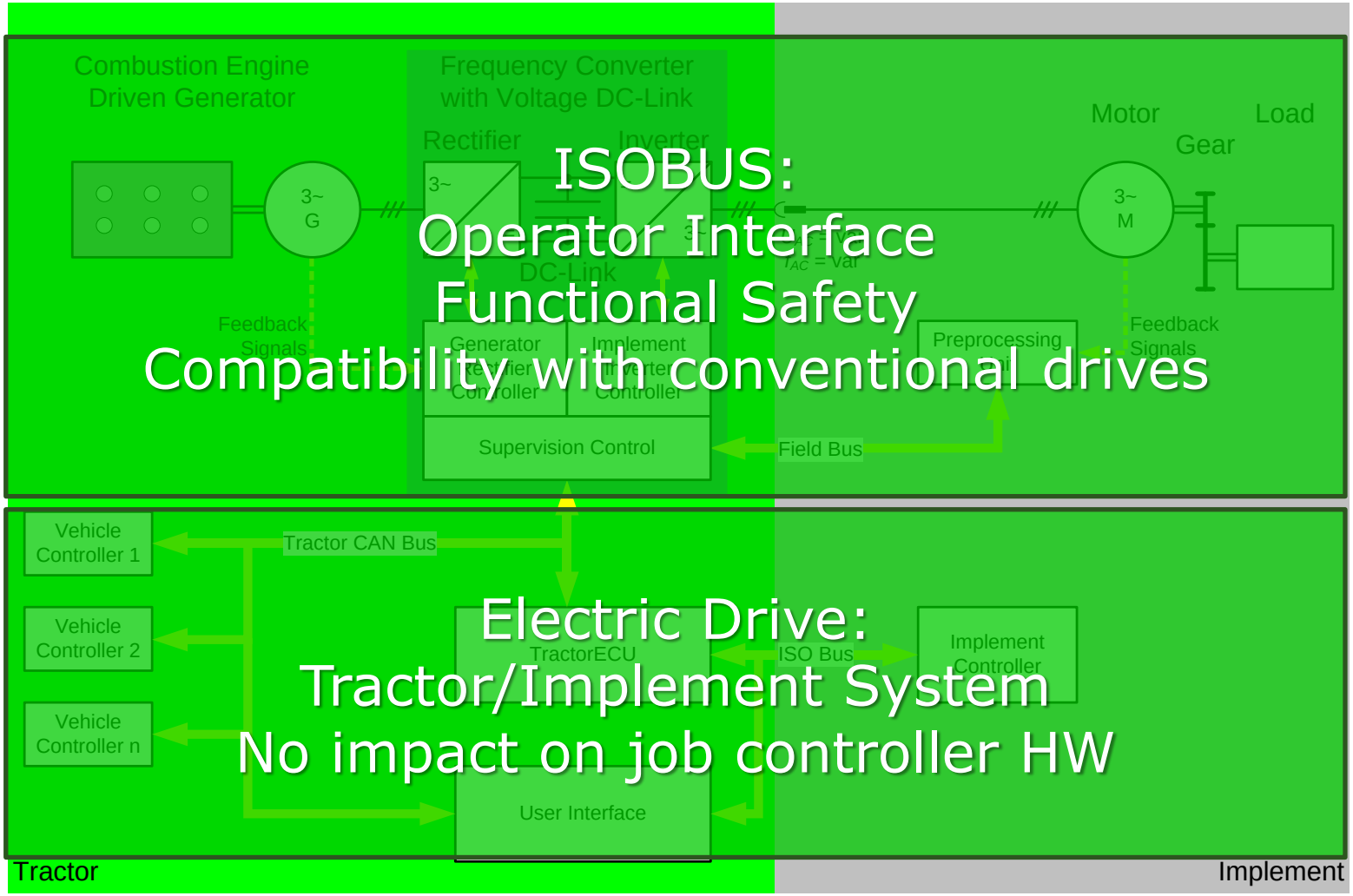
Traktor/Implement-Electrification: Architecture



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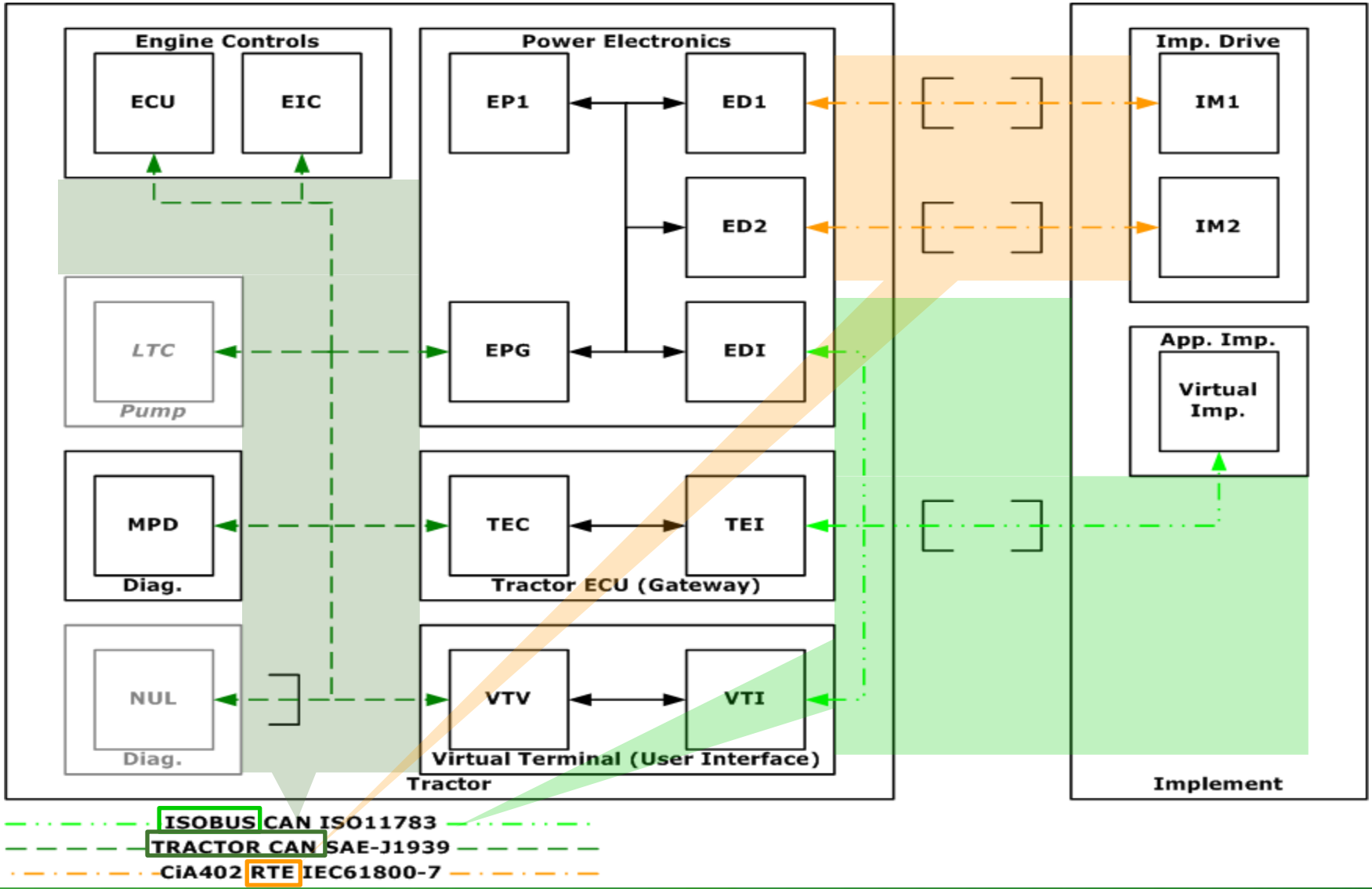
TIE – Communication Architecture (1/2)



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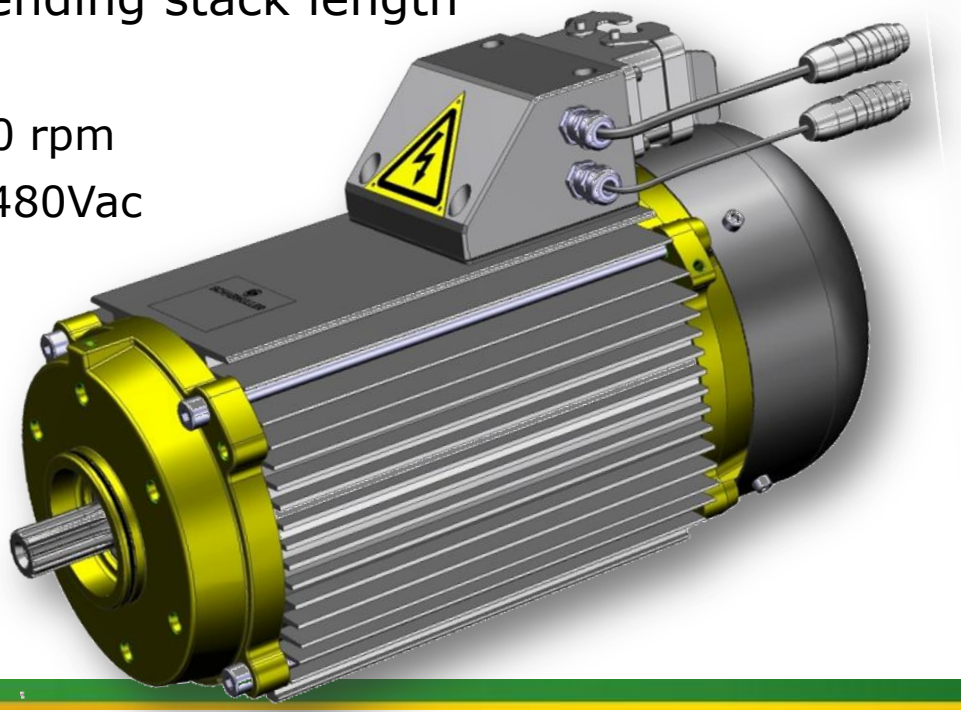
Electric Machines for Implements

Family of electric machines – one example

- Modular concept
  - high torque density PMSM concept
  - same stator/rotor diameter for the family
  - power/torque increase by extending stack length
    - e.g. 7kW – 13kW – 20kW
    - rated speed, e.g. 5000 – 6000 rpm
    - rated voltage, e.g. 400Vac – 480Vac



Controller Architecture: FPGA & EtherCAT

Control of the Power Electronic Box

One centralized processor controls:

- Combustion engine driven Generator (Induction Motor)
- Two implement motors (PMAC)

Both implement motors use EtherCAT as rotor angle feedback bus:

- 250 µs cycle time for position feedback (125 µs is also possible)
- Loss of communication (=connection) detection
- FPGA contains two independent EtherCAT Masters with limited functionality:
  The frame is generated and received by programmable hardware (VHDL)
  The processor is only needed for initialization and fault handling after shut down of the implement motor
- System on a chip with minimal delay

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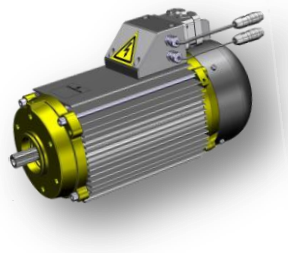
Slave Architecture / EtherCAT based EIB

Electrification Interface Box (EIB)

- One EIB for each load on implment
- EtherCAT Slave ASIC ET 1100
- Simple Microcontroller (PIC)
- 250 µs cycle time (limited by the µC)
- The PDO Tx object includes all parameters that are required at runtime.
- The total PDO size of the 0x2000 object is 144 bit.
- Enough space to tunnel e.g. ISOBUS (CAN) … and more
- Allows transfer of load type data … and more

Object:SIX	*Description*	*Type*
0x2000:01	Temperature	UINT8
0x2000:02	Direction	BOOL
0x2000:04	Speed	UINT32
0x2000:05	Position	UINT32
0x2000:06	ErrorRegister	UINT32
0x2000:07	Reserved1	INT16
0x2000:08	Reserved2	UINT16



EtherCAT

Power

Input / Output shaft feedback

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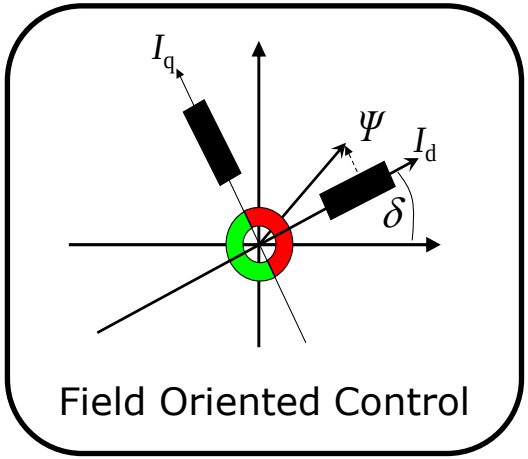
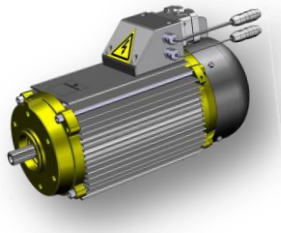
Control Performance: Closed loop PMSM

FPGA based Motor Control

- Enhanced Space Vector Pulse Width Modulation
  8 kHz switching frequency
- Sigma-Delta current measurement
  with digital EMI filtering
- I²t heat model to protect the IGBT modules
- Field Oriented Control (FOC)
  16 kHz current loop update frequency
  $\cos(\varphi) \approx 1$
- PI velocity loop
  4 kHz update (= 250 µs EtherCAT cycle time)
- Over-speed detection
- Programmable acceleration and deceleration ramp



Field Oriented Control



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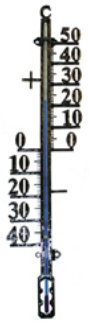
EtherCAT on Tractor/Implement



Tractor / Implement Challenges

- Automotive temperature range / very high humidity
- EMI
- Combustion engine is not part of the control loop
  Handling of limited power requires fast communication
- Only approved slaves (= implements) are allowed to be powered
- Closing the control loops must be flexible

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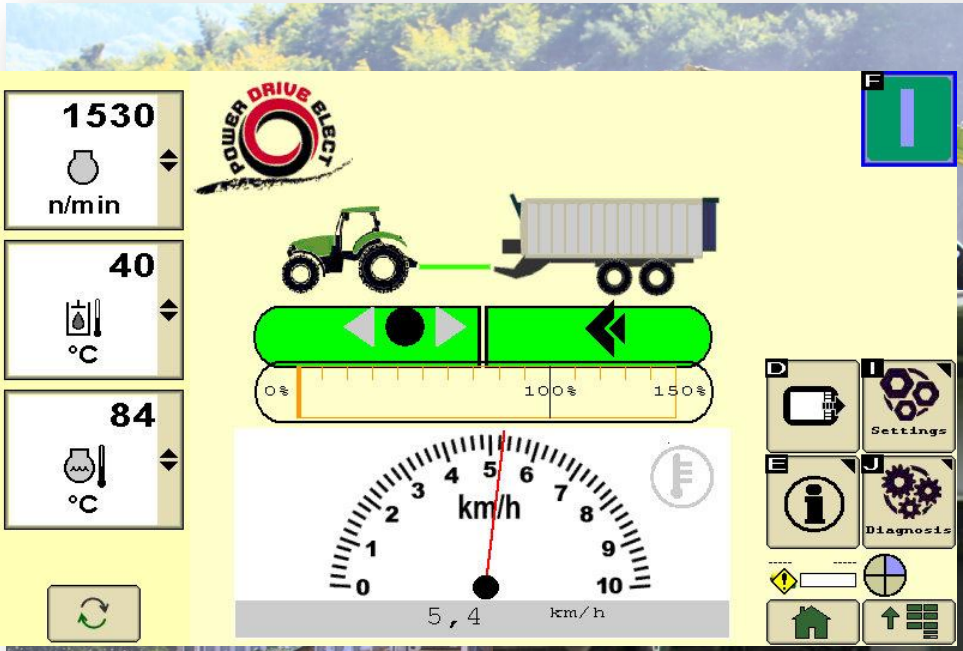
Tractor/Implement Electrification: Objectives

- **Identification of Implement** via ISOBUS
  - Implement function related control via implement job controller
- **Support of both AC- and DC-architectures on implements**
- **Closed loop control of implement loads**
- **Commonality**
- **System level diagnostics**
- **One cable"Plug & Play"**
  - **Safety**
  - **Function & performance (electronic type sheet)**
  - **Identification of load per receptacle**

Application: Traction Axle, Trailer



+8kN
Tractive force

"wheel tracing signific

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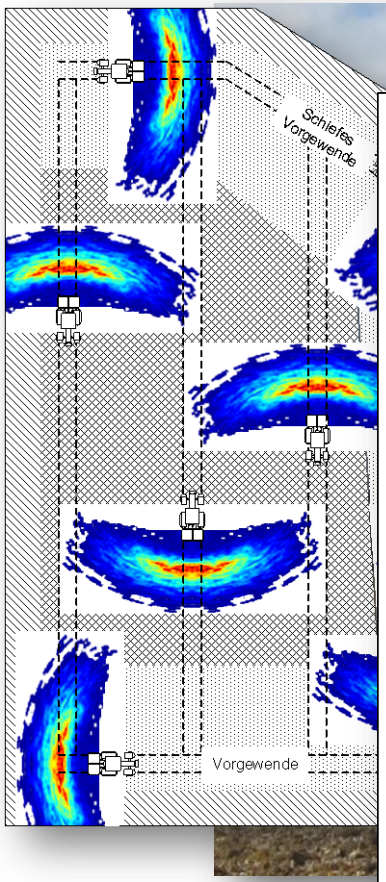
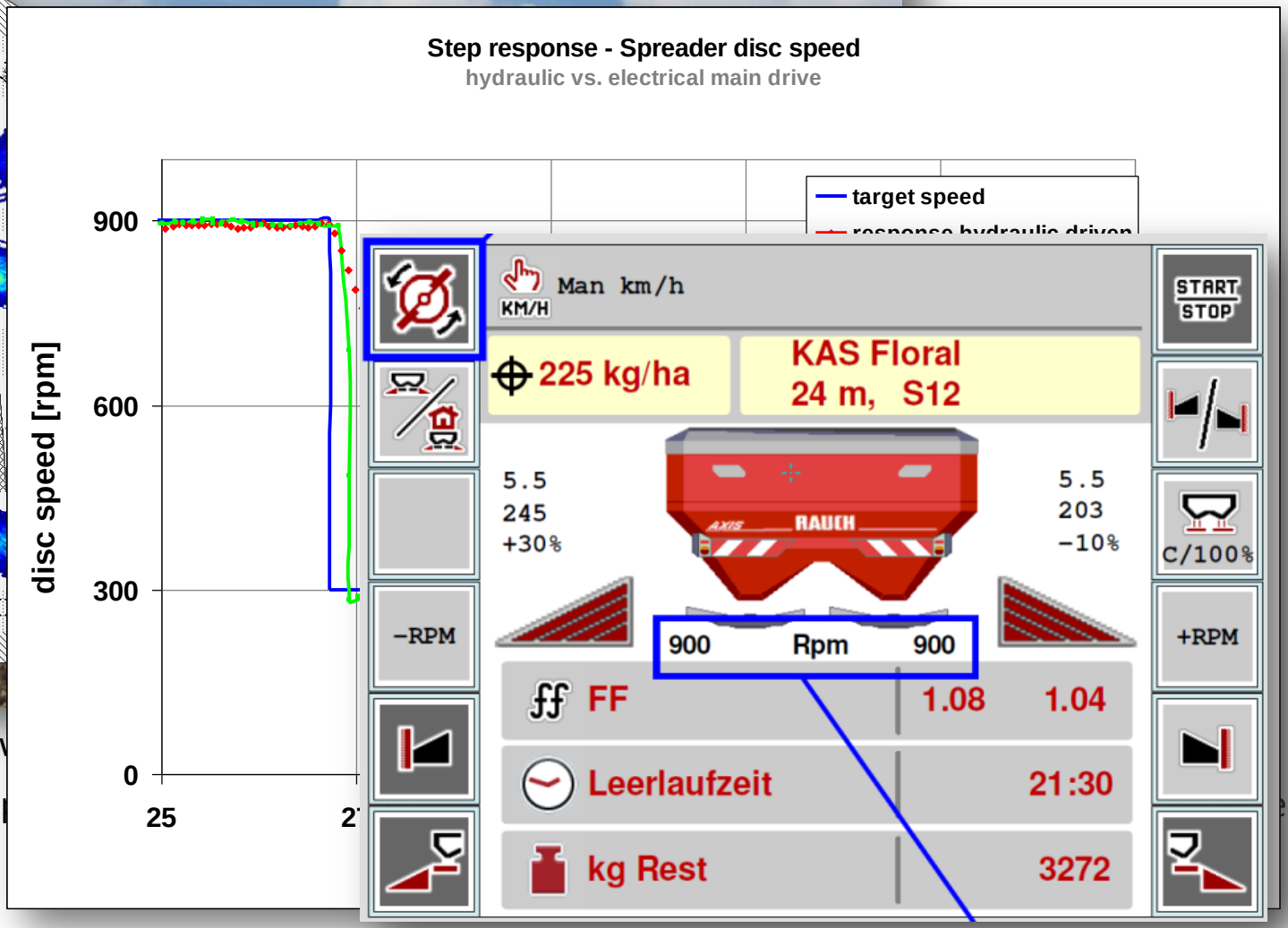
Application: Electrified Fertilizer Spreader





"reliable operation v

„performance like sp
cooperator

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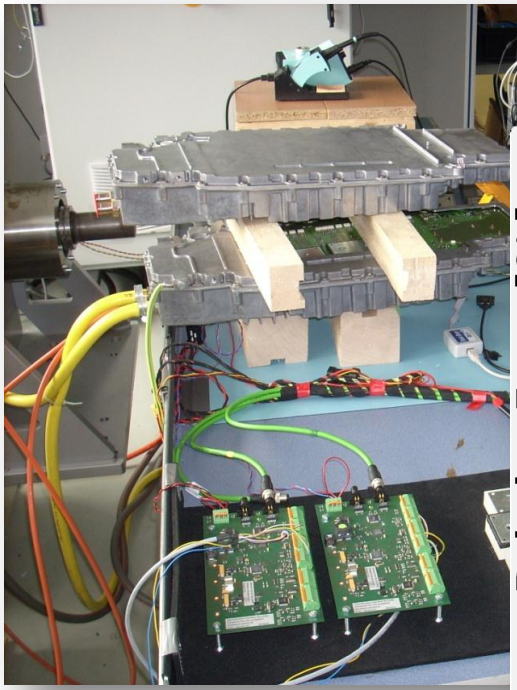
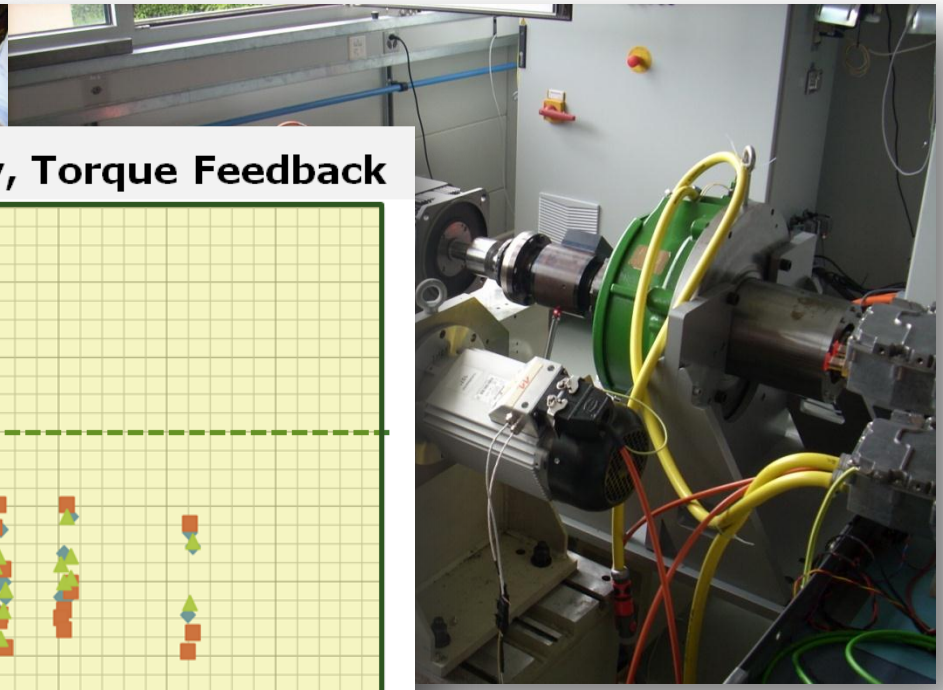
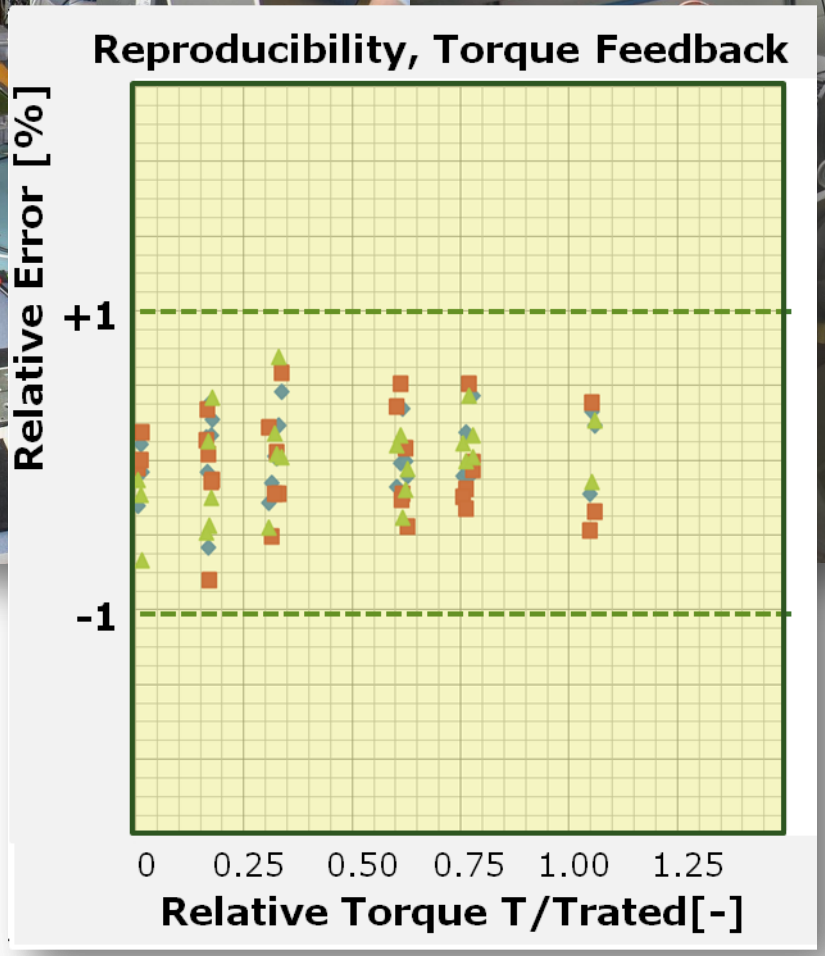
Torque Feedback







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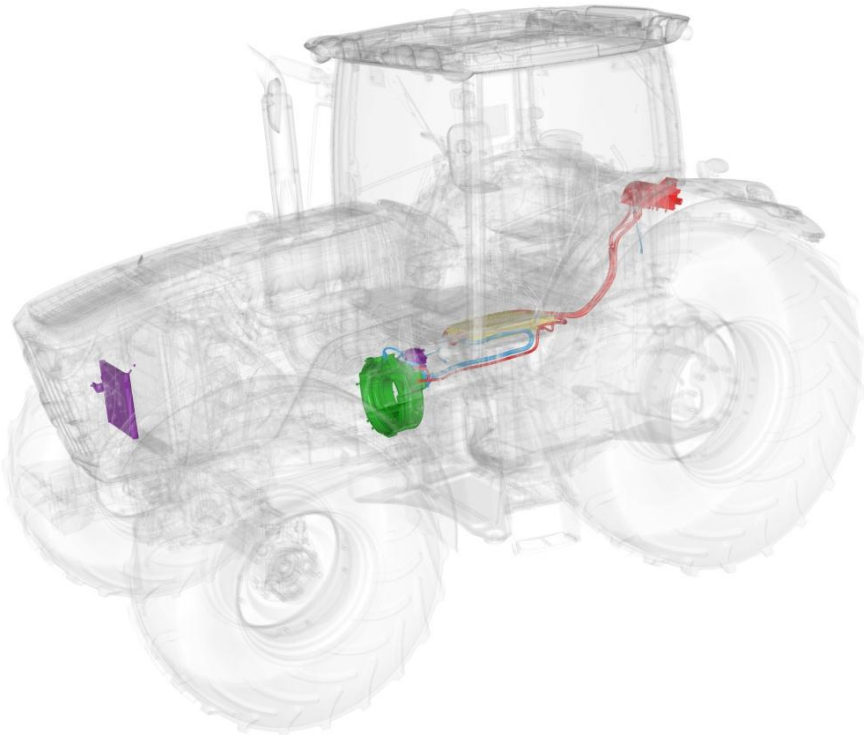
Summary

- John Deere 6210RE: The next level of system integration
- Coordinated development: implements & tractors
- High performance communication:
  - Plug & Play
  - Closed loop control
  - …
- Remaining gaps need to be filled



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