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)

- Electric Drive Systems
- Excellent Controllability
- Improved Distribution
- Optimum Integration

Tractor: Power Generation

HV Interface

Customer Value Chain

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
Tractor/Implement Electrification: Configurations

JD 6210RE
Best flexibility
Increased effort on tractor
Tractor/Implement Electrification: Configurations

One Interface: all options

AEF PG7
Physical HV Power Interface (ref. AEF PG7)

- **GEN2: lid top mounted**
- **Connector handle**
- **Power contacts**
  - DC / AC
- **Leading contact for EPBC**
- **Real time Ethernet compliant data interface**
- **Metal bushing on plastic cover**
- **Break away feature**
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)
Traktor/Implement-Electricrification: Architecture

ISOBUS:
Operator Interface
Functional Safety
Compatibility with conventional drives

Electric Drive:
Tractor/Implement System
No impact on job controller HW

Combustion Engine Driven Generator
Frequency Converter with Voltage DC-Link
Rectifier
Inverter
Generator Controller
Implement Controller
Supervision Control

Motor
Gear
Load
Preprocessing Unit

Vehicle Controller 1
Vehicle Controller 2
Vehicle Controller n

Field Bus

Tractor CAN Bus

ISO Bus

User Interface

User Interface

ISO Bus

Implement

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TIE – Communication Architecture (1/2)
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
Electrification Interface Box (EIB)

- One EIB for each load on implement
- 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

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Input / Output shaft feedback
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 \( \mu \)s EtherCAT cycle time)
- Over-speed detection
- Programmable acceleration and deceleration ramp
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
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

“wheel tracing significantly improved in cross hillside operations..."

+8kN
Tractive force
Application: Electrified Fertilizer Spreader

“reliable operation w/o any incident” : customer/test cooperator

"performance like spreader speed, dynamic behavior and torque feedback are excellent": customer/test cooperator...

Step response - Spreader disc speed
hydraulic vs. electrical main drive

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<th>time [sec.]</th>
<th>disc speed [rpm]</th>
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<tr>
<td>0</td>
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<td>600</td>
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<tr>
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Target speed
Response hydraulic driven
Response electric driven

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Torque Feedback

Reproducibility, Torque Feedback

Relative Error [%]

-1

+1

Relative Torque T/Trated [-]

0 0.25 0.50 0.75 1.00 1.25
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