A New Approach for Increasing Efficiency of Agricultural Tractors and Implements

Project ID: **ace161**

2021 DOE Vehicle Technologies Office
Annual Merit Review

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Overview

Timeline

- Start date: October 2020
- End date: January 2024
- Percent complete (May 2021): 25%

Budget

- Total project funding: $3,125,773
  - DOE share: $2.5M
  - Contractor share: $625,773
- Funding for FY 2021: $1,051,586
  federal ($ 809,969)

Partners

- Purdue University – project lead
- Case New Holland Industrial (CNHi)
- Bosch Rexroth
- National Renewable Energy Laboratory (NREL)

Barriers and Technical Targets

Barriers

- Improving the efficiency of commercial agricultural vehicles can reduce fuel consumption and provide decreased operating costs for American farms.
- Many agricultural vehicles are reliant on fluid-power for their work and drive circuits due to their ability to supply high specific power density and tolerate harsh conditions. However, current fluid-power systems have poor efficiency.
- State of the art fluid power systems have excessive throttling losses.

Technical Targets

- increase (double) the energy efficiency of the overall hydraulic transmission system of tractors and their implements, by *reducing throttling loss*
- Achieve a payback period < 2 years

Relevance

- When an agricultural tractor is connected to a high-power demand implement (a planter, a bailer, etc.) the energy efficiency of the high-pressure system that powers the implement is as low as 20%.
- There is a tremendous opportunity to increase this poor energy efficiency through a re-design of the hydraulic control system, though the use of modern electro-hydraulic technology.
- Commercial success a new fluid power technology is ensured by meeting cost requirement, but also allow compatibility across tractors and implements of different brands and technologies.

Objectives

to develop and demonstrate a novel Multi Pressure Rail (MPR) concept for hydraulic control systems of agricultural tractors and their implements capable of:

- ✓ doubling the energy efficiency of the overall hydraulic transmission system of the tractor and implement
- ✓ reducing the energy consumption of the in-tractor fluid power (FP) functions by ≥15%
- ✓ achieve a payback period < 2 years
- ✓ preserve compatibility with state-of-the-art machines
- ✓ demonstrate the technology on a Cash Crop High tractor and a 16-row planter.

Reduction of Energy Cost

Cleaner Energy Technology

: focus of project activities in BP1

Approach and Milestones

Approach

Project activities occurs in three domains:

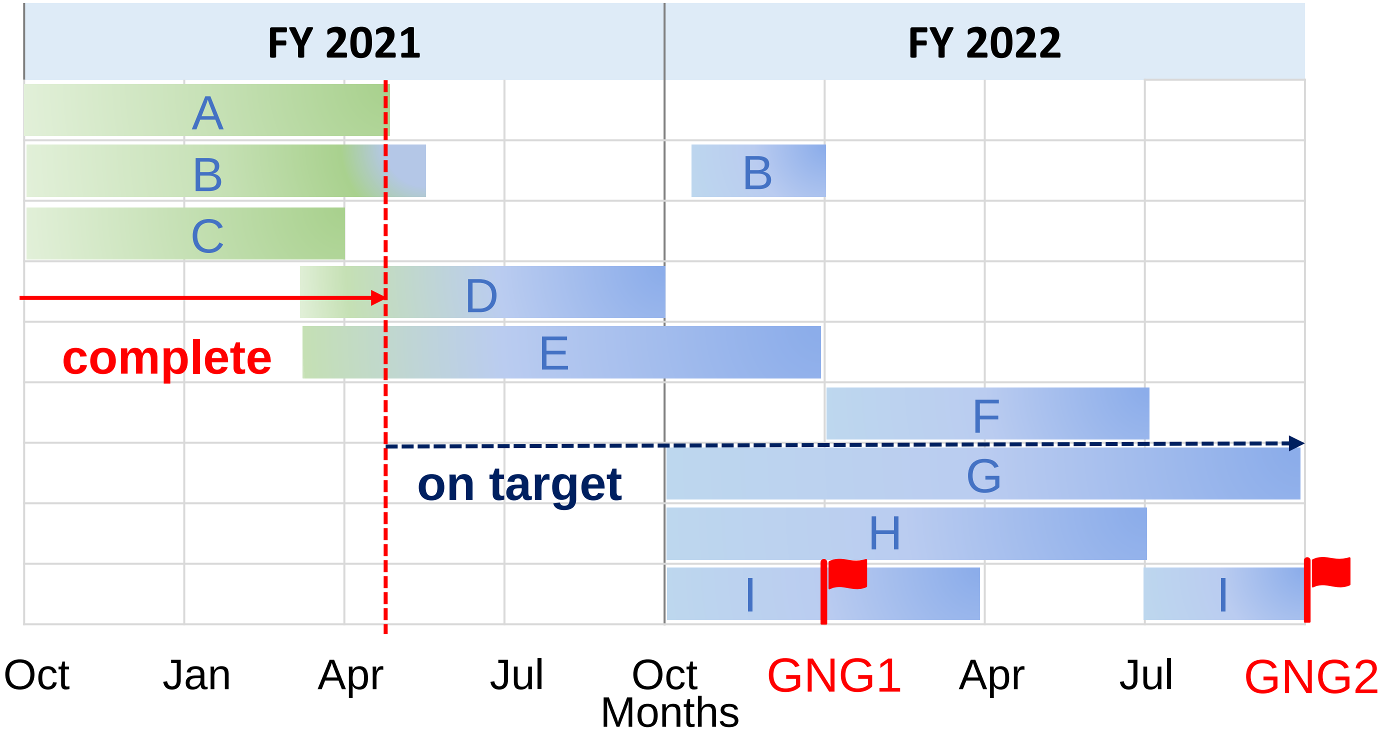
O1. MPR Configuration. To determine the configuration of the MPR system (optimizing energy efficiency)

O2. MPR Compatibility. To develop cost-effective methods for MPR machines compatible with traditional technology

O3. Technology Demonstration. To establish proof-of-concept MPR systems and experimentally demonstrate the energy efficiency advantage and the compatibility features of the technology on tractor-implement prototypes

Milestones *(SMART Milestones denoted by *)*

A. Instrumented tractor implement (O3)*
B. MPR system simul. (O1)
C. MPR selection (O1)*
D. Baseline measurements (O3)*
E. MPR standalone tests
F. MPR prototype 1st gen. (O3)*
G. MPR solution for compatibility (O2)*
H. Compatible MPR sizing, 2nd gen. (O2)*
I. MPR prototype 1st generation measurements (O3)*



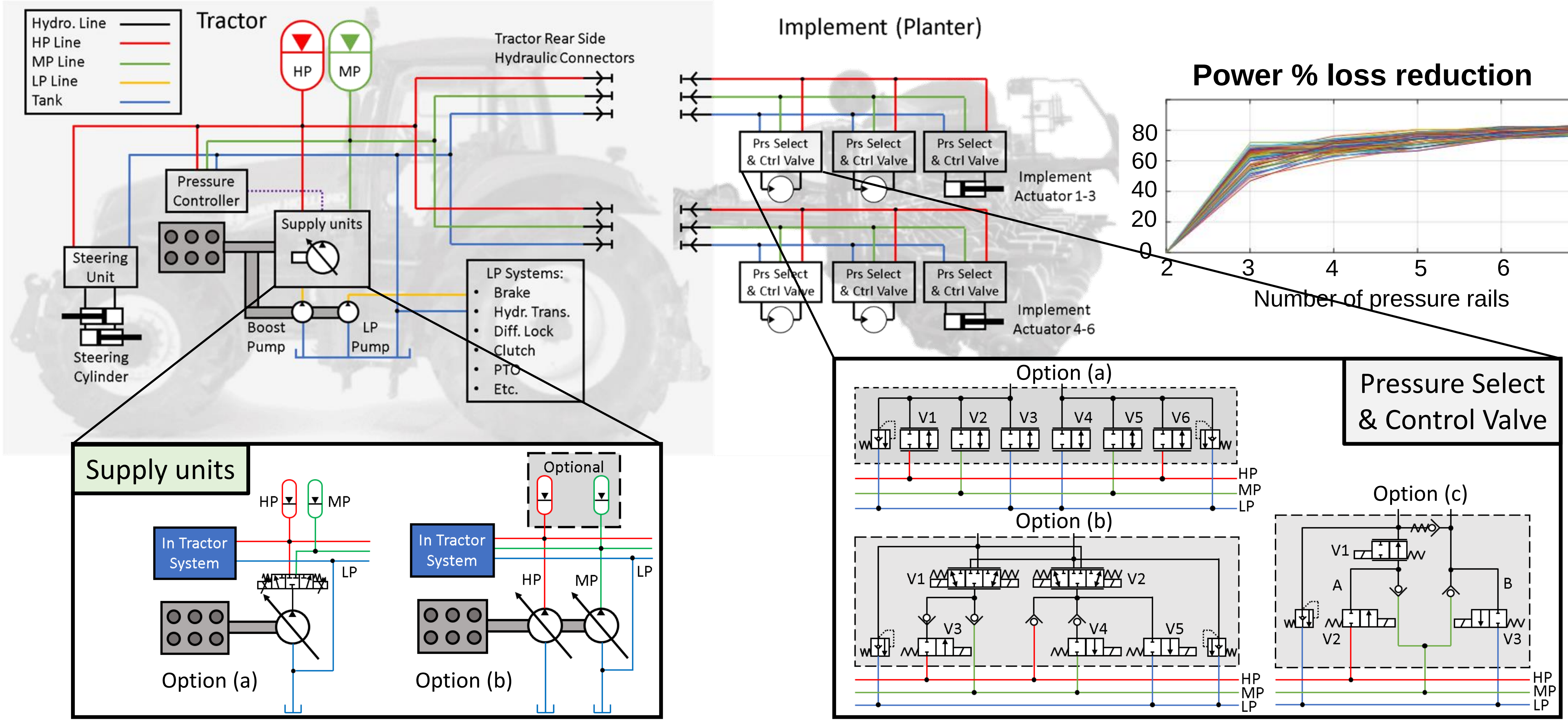
Go/No-Go (GNG) 1: The simulated MPR system delivers >60% higher efficiency than the baseline machine.*

GNG2: The measured MPR system overall energy efficiency MPR system >40% of the baseline configuration.*

Technical Accomplishments

- Definition of the architectures for the MPR system for a tractor-implement.
- Analysis of different arrangements for the supply type and different actuator control valves

MPR Configuration (O1)



Technology demonstration (O3)

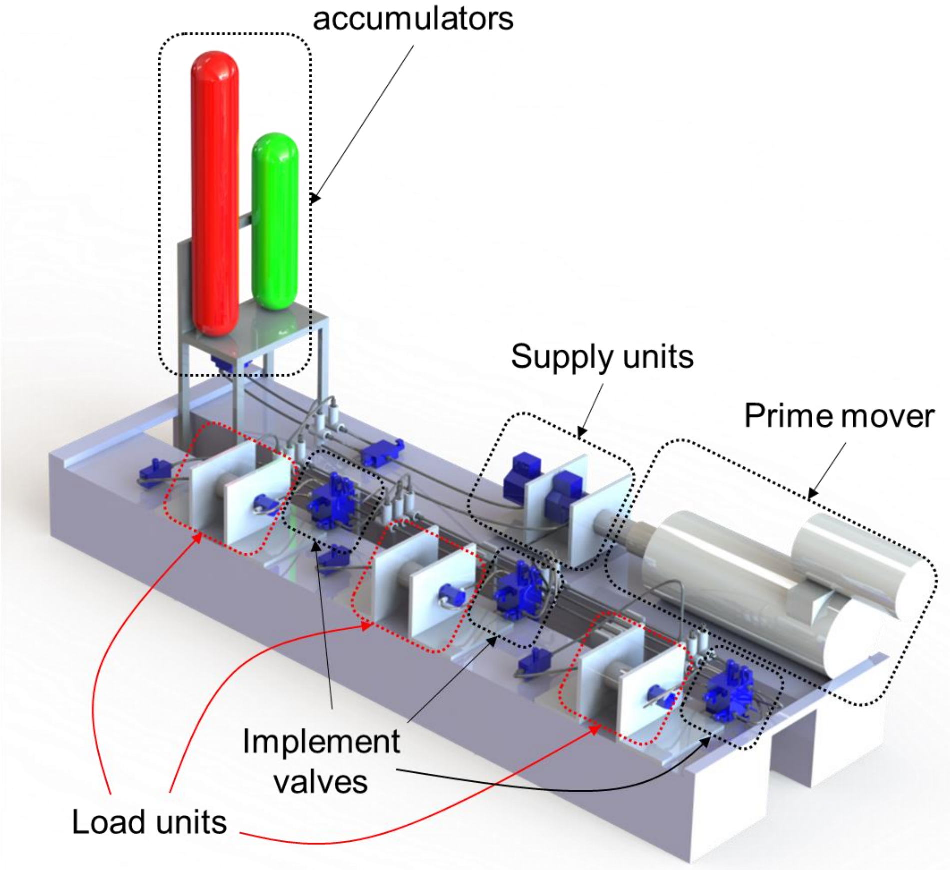
- A tractor and an implement were selected with input from Case New Holland
- Both vehicles were instrumented for measuring hydraulic power usage
- A test plan for the typical use of the high-pressure system was designed and implemented. This fills the lack of specific standard for agricultural vehicles.
- A stationary test rig for testing MPR components and control strategies has been implemented with Bosch Rexroth

Test plan

Stationary lab test	Field tests

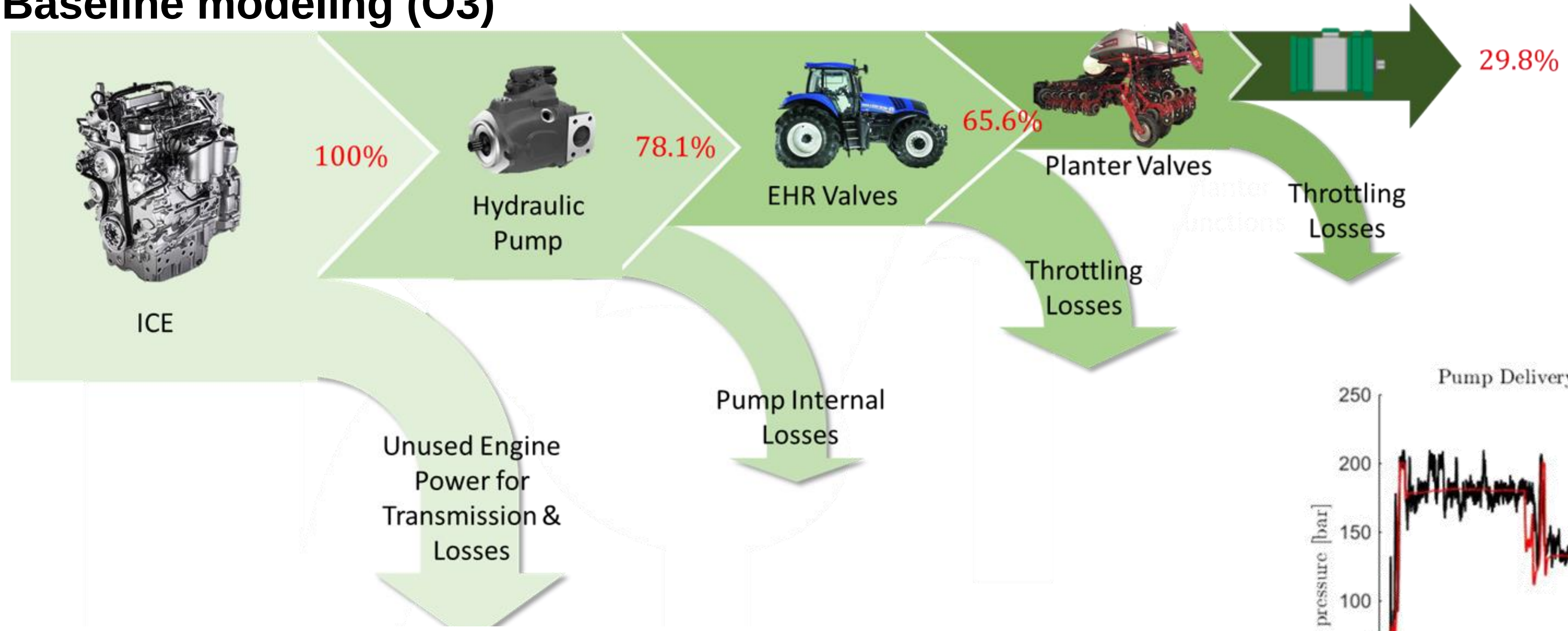
CNH T8.435 Tractor

Case IH Early Riser 2150 Planter

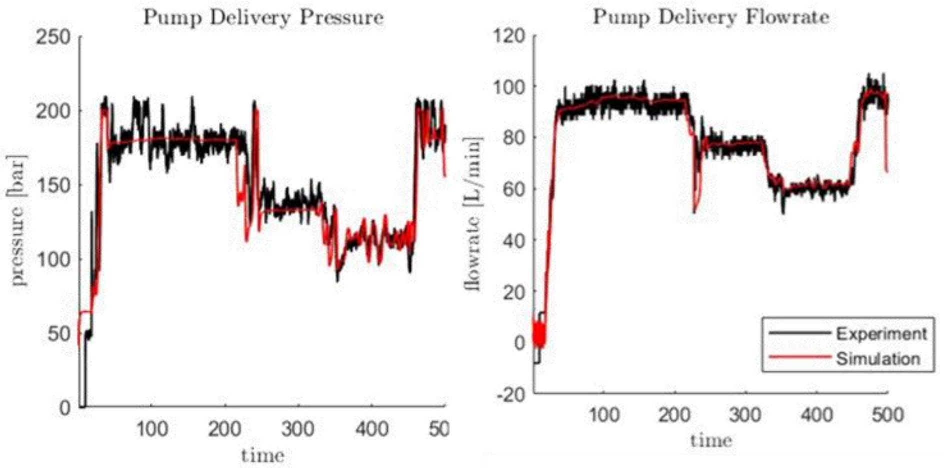


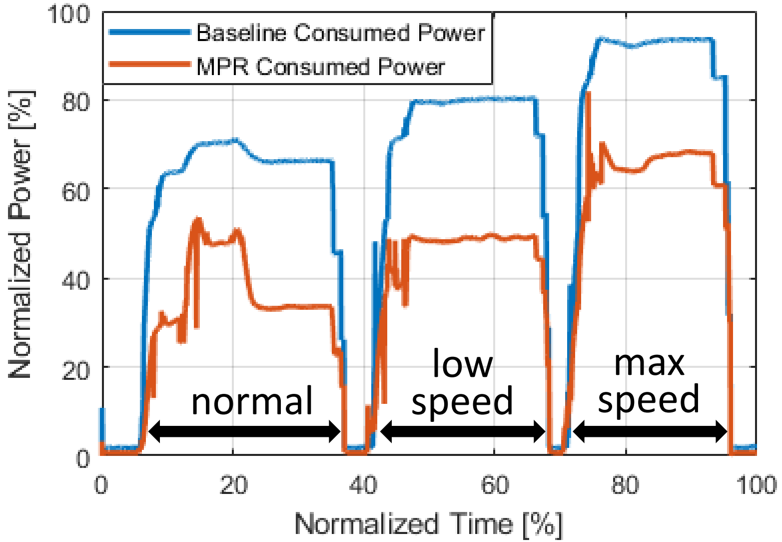
Technical Accomplishments

Baseline modeling (O3)



29.8% efficiency measured in a lab test excluding down force cylinders





- A simulation model for the commercial tractor-implement system was developed in **Amesim** and validate against baseline tests results
- This model permits detailed analyses of energy flows and efficiency
- The model was used for designing a preliminary MPR system inclusive of a controller that manage the pressure in the rails
- **The MPR systems allows halving energy consumption** (simulation)

Collaboration

Collaborators	Relationship	Extent of the collaboration
PURDUE UNIVERSITY *PI: Andrea Vacca*	**Prime** University Outside VTO	• Purdue leads the activities related to the MPR design, for both the compatible and non-compatible implementation. All the simulation and the testing activities on the tractor, the implement and the stationary test rig are performed at Purdue
CNH INDUSTRIAL *Gary Kassen*	Sub Industry Outside VTO	• CNHi supports the simulation, testing, and physical modifications of both the tractor and the implement systems to build working prototypes. Finally, CNH provides expert operators and guidance to identify the representative drive cycles for the reference vehicles
rexroth A Bosch Company *Enrique Busquets*	Sub Industry Outside VTO	• Bosch Rexroth leads activities related to the fabrication of the EH components for the MPR system. Rexroth helps in the implementation of the stand-alone test rigs and the vehicle prototypes, and in the design of the most suitable sensors and control strategies
NREL Transforming ENERGY *Chen Zhang*	Sub National Lab Outside VTO	• NREL participates in all experimental activities involving the reference vehicles. The lab will derive control strategies for the proposed MPR technology through machine-learning methods to enable optimal energy savings for various tractor-implement configurations. NREL will also participate in cost analysis tasks

Proposed Future Research

	Key Challenges	Future Work
FY2021	• Baseline measurements on a reference tractor-implement system, through field tests	1. Test Plan Definition 2. Field Tests 3. Drive Cycle Simulation
FY2021	• MPR system optimization and control management	1. Dynamic control 2. Rule-Based Control
FY2021	• Stationary lab tests to test basic components and control strategies	1. Stand-Alone Tests 2. Control Design Validation
FY2022	• Implement and test the MPR configuration found in BP1 to the reference CCH tractor & 16-row planter	1. Prototype Preparation and Testing 2. Model Validation from Stand-Alone Tests 3. Model Validation (1st Gen. Prototype)
FY2022	• Define an architecture of the MPR system suitable for prototype implementation in BP3	1. Definition of Compatible MPR Layouts 2. MPR Layout Definition and Component Sizing 3. Test of control strategies in Stand-Alone tests
FY2022	• Market analysis	1. Marketability of MPR solutions

Any proposed future work is subject to change based on funding levels

Summary

Accomplishments

- Fully instrumented tractor-implement system
- MPR architecture and control formulated
- Formulation of a test plan for the hydraulic system of agricultural tractors
- Development and validation of a simulation model
- Stand-alone test rig design.

Successful project management through weekly and monthly meetings. Expected milestones delivered on time.

DOE Impact

An opportunity for US industry to transform agricultural equipment technology through a high-efficient method that offers the advantage of being compatible with existing state-of-the-art technology.

Technical Highlights

- The proposed technology doubles the energy efficiency of the overall tractor-implement hydraulic system
- Experiments set to demonstrate the technology in an actual agricultural system

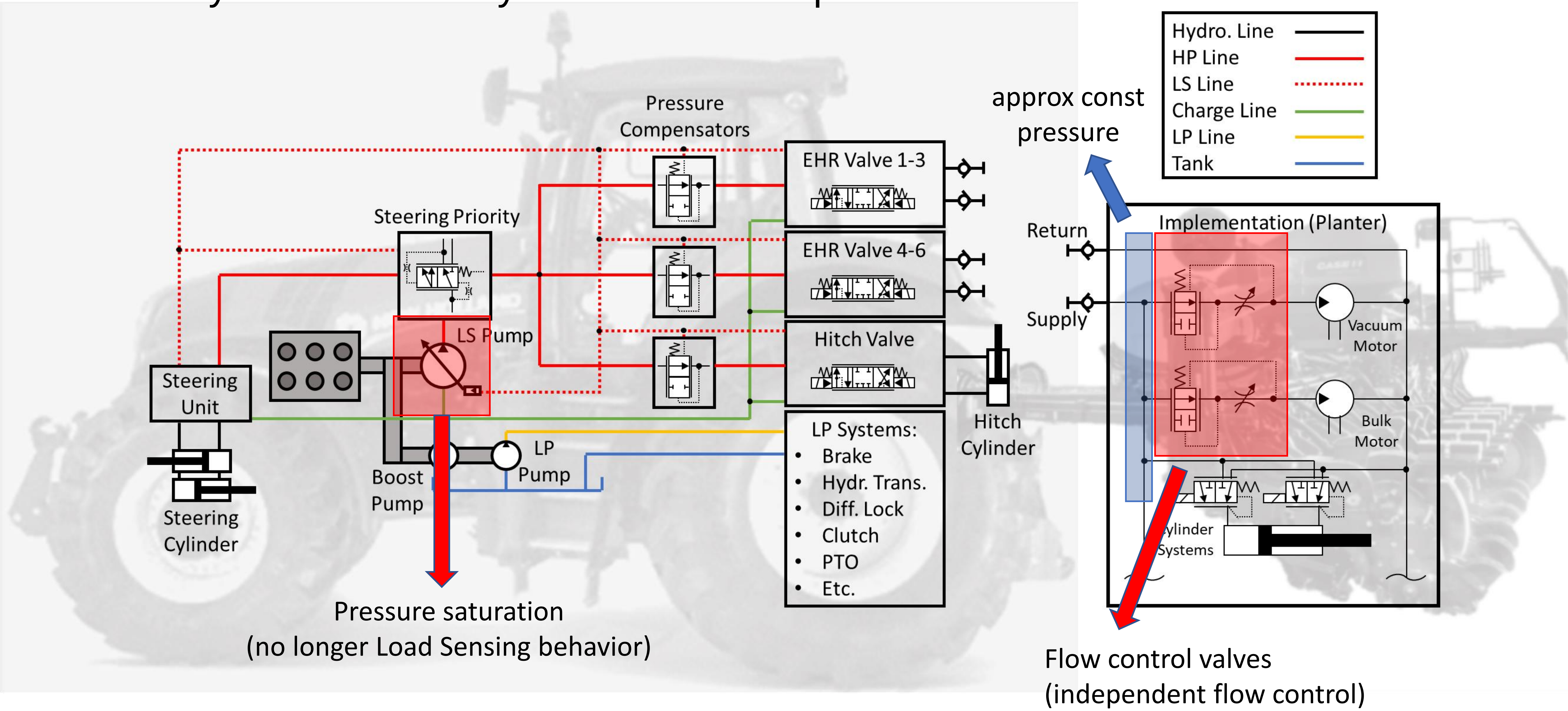
Collaborations

Close cooperation between an OEM, a tier 1 component supplier, a national lab and a University creates a unique platform for technology innovation

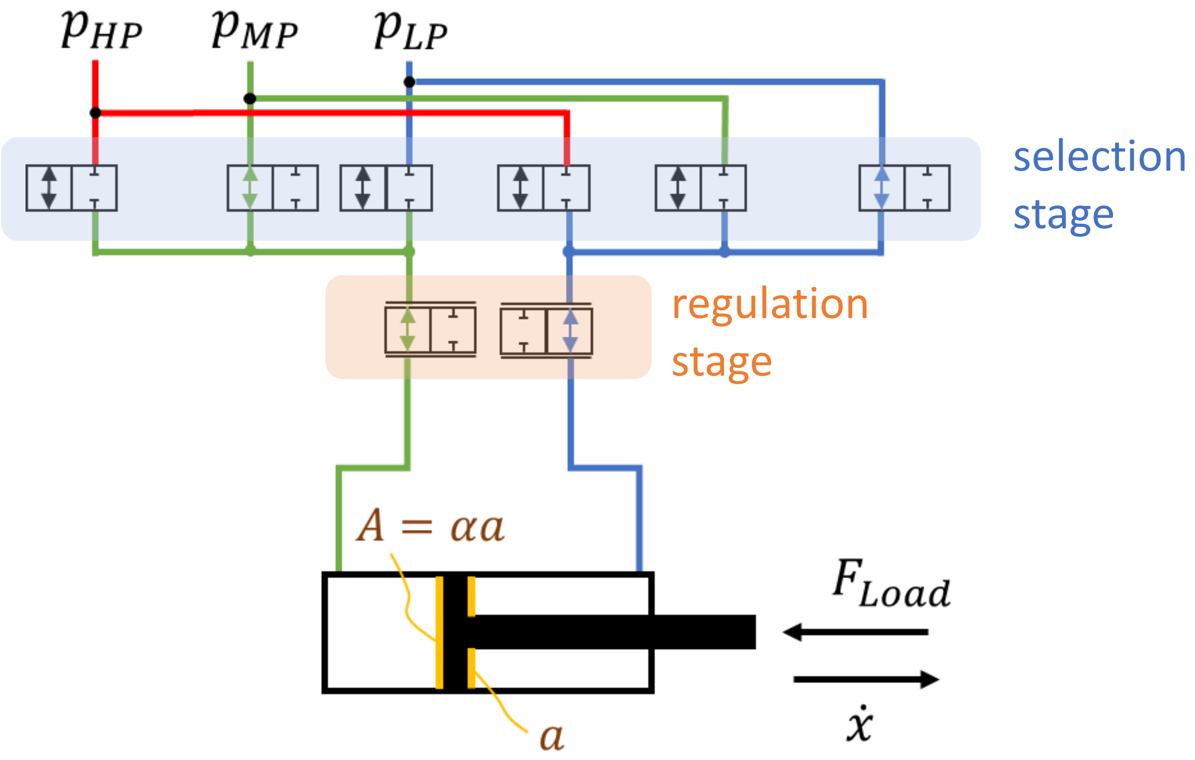
CNH INDUSTRIAL   rexroth A Bosch Company   NREL Transforming ENERGY

Technical Back-Up

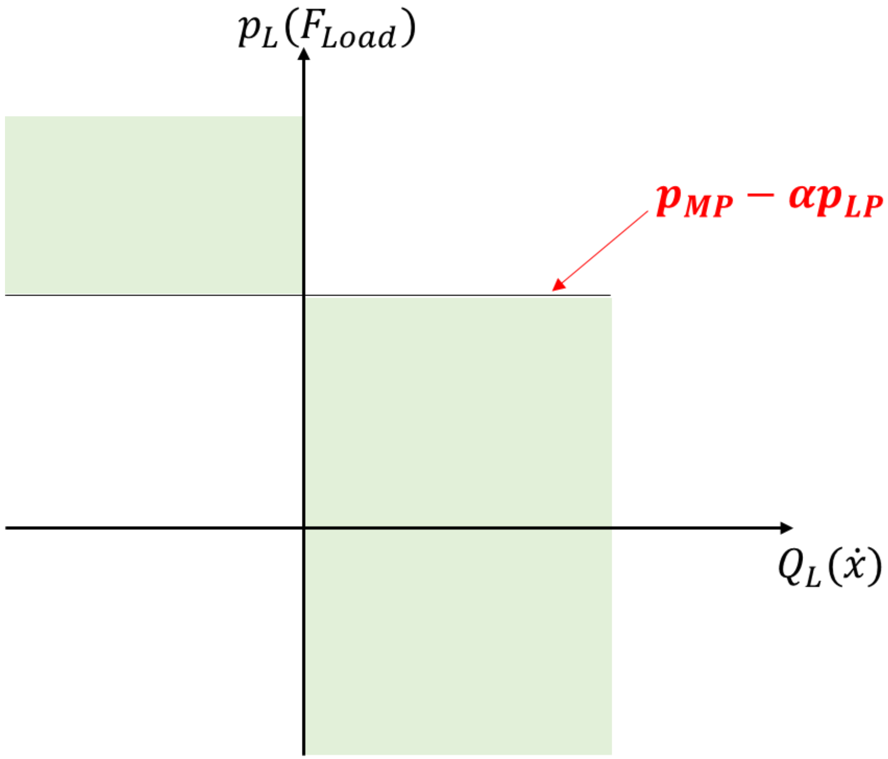
Cause of system inefficiency in the Tractor-Implement circuit



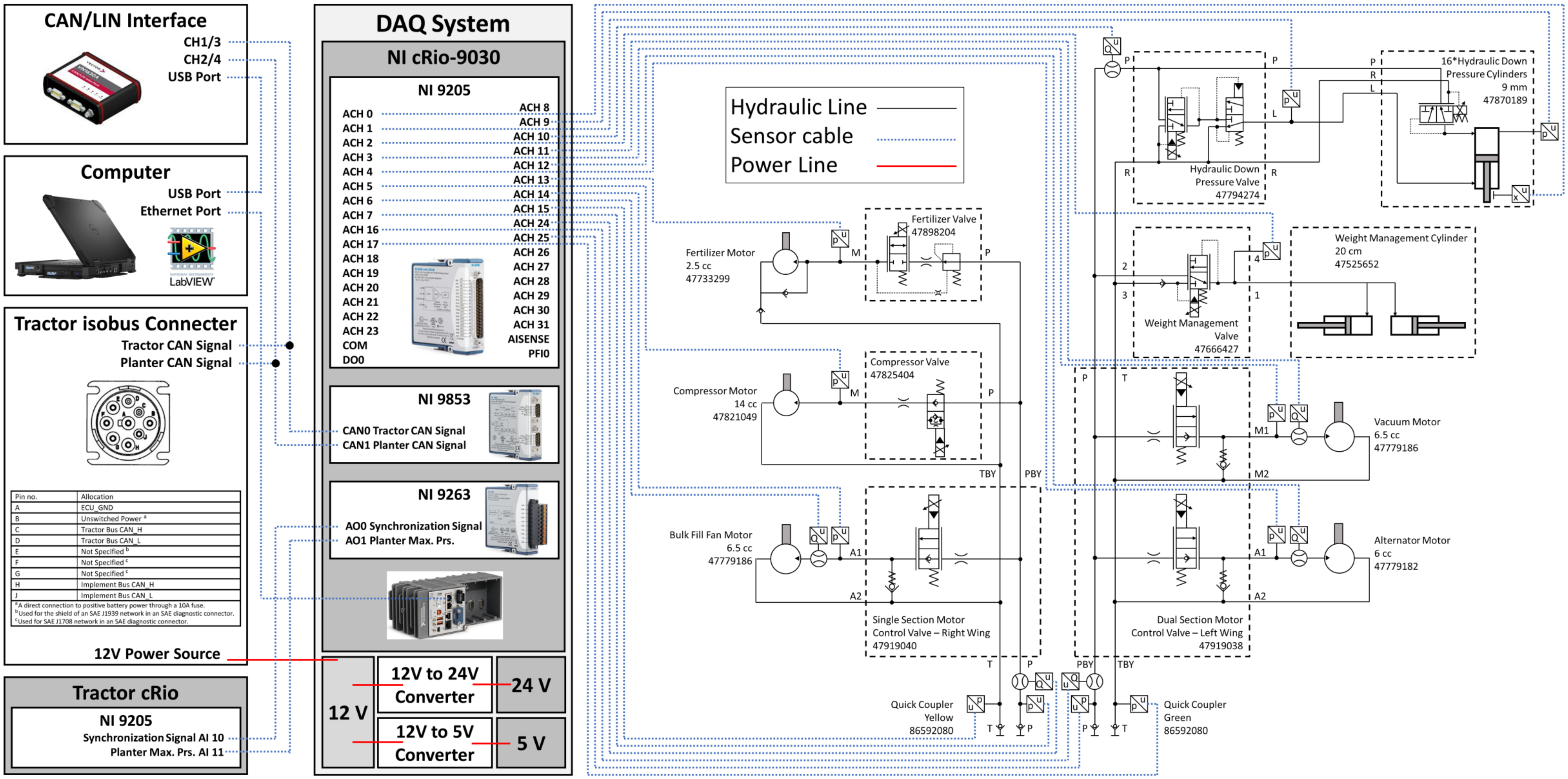
MPR Operation



		p_1		
		HP	MP	LP
p_2	HP			
	MP			
	LP		$\boxed{X}$	



Implemented Instrumentation and Data Acquisition System (Planter)



Pin no.	Allocation
A	ECU_GND
B	Unswitched Power [a]
C	Tractor Bus CAN_H
D	Tractor Bus CAN_L
E	Not Specified [b]
F	Not Specified [c]
G	Not Specified [c]
H	Implement Bus CAN_H
J	Implement Bus CAN_L

[a] A direct connection to positive battery power through a 10A fuse.
[b] Used for the shield of an SAE J1939 network in an SAE diagnostic connector.
[c] Used for SAE J1708 network in an SAE diagnostic connector.

Amesim model implementation