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Giuseppe Pellizzi Prize 2024

33rd Members' Meeting of the Club of Bologna

November 10, 2024

METHODS TO REDUCE ENERGY CONSUMPTION IN THE HYDRAULIC SYSTEM TOWARD THE NEXT GENERATION OF GREEN, HIGH-EFFICIENT AGRICULTURAL TRACTORS

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CNH
PURDUE UNIVERSITY
Maha Fluid Power RESEARCH CENTER

About Me

Xin Tian

Maha Fluid Power
RESEARCH CENTER

CNH sponsorship

2013

2017

2022

current

Bachelor of Engineering
Xi'an Jiaotong University
Mechanical Engineering

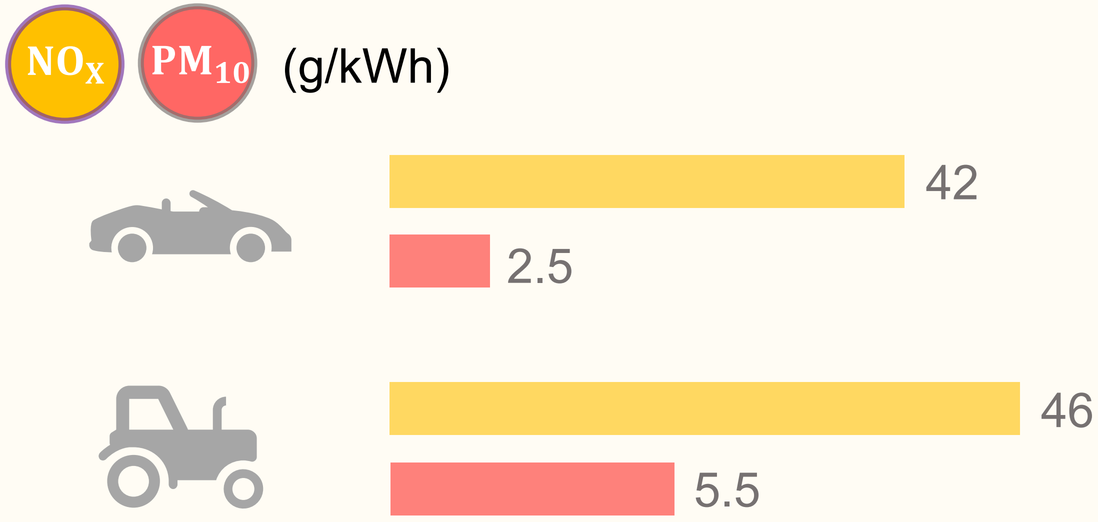
PhD (Direct PhD)
Purdue University

System Modeling Engineer
Research & Development

Integrated Validation - Design Analysis & Simulation

Background and Motivations

2016, EU[1]



Fluid Powered System Efficiency Overview[2]	
Sector	Efficiency
Mobile (excavators, loaders and tractors)	30%
Industrial Hydraulics	50%

[1]. Z. Samaras and K. H. Zierock, “Off-road vehicles: a comparison of emissions with those from road transport
[2]. Love, Lonnie J., et al., "Estimating the impact (energy, emissions and economics) of the US fluid power industry." Oak Ridge National Laboratory, Oak Ridge, NFPA, TN (2017).

Challenges on Agricultural Machines

Challenges

- Complexity on auxiliary supply circuit layout
- Highly variable duty cycles

Power Loss Study

power consumption characterization

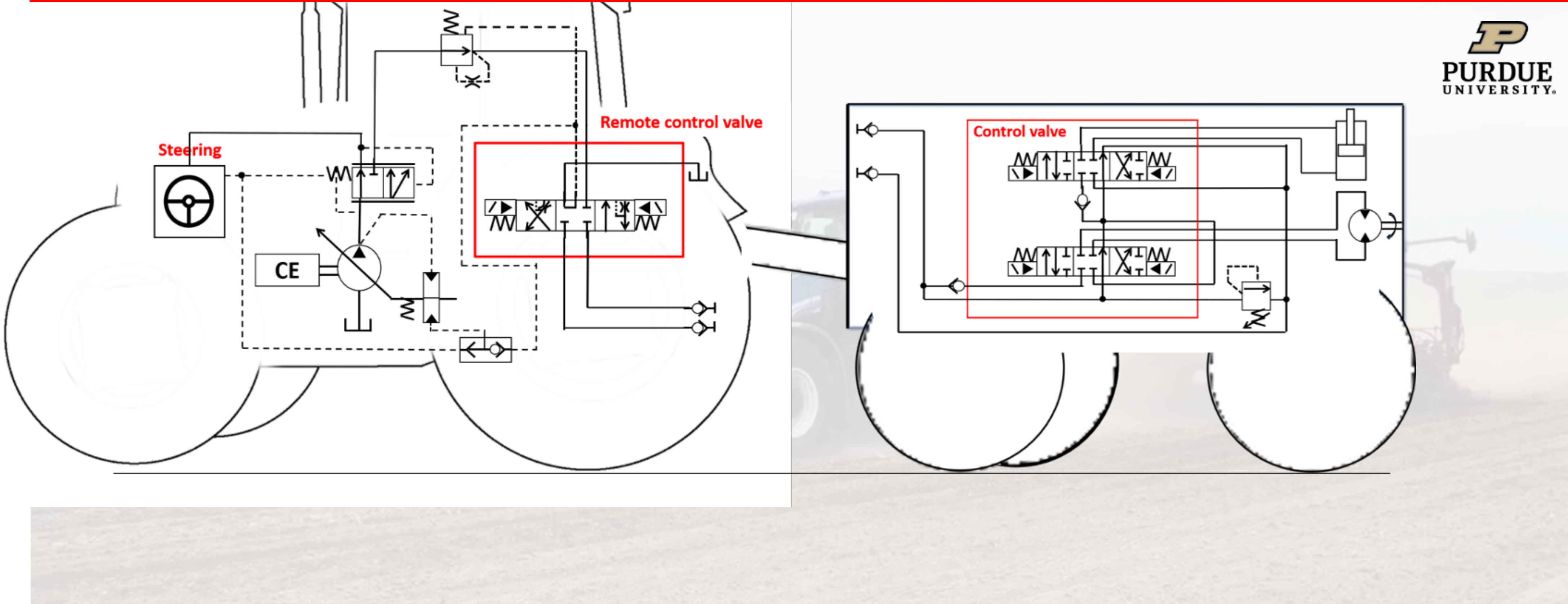
High-efficient & Cost-effective Solutions

performance & efficiency

components optimal sizing

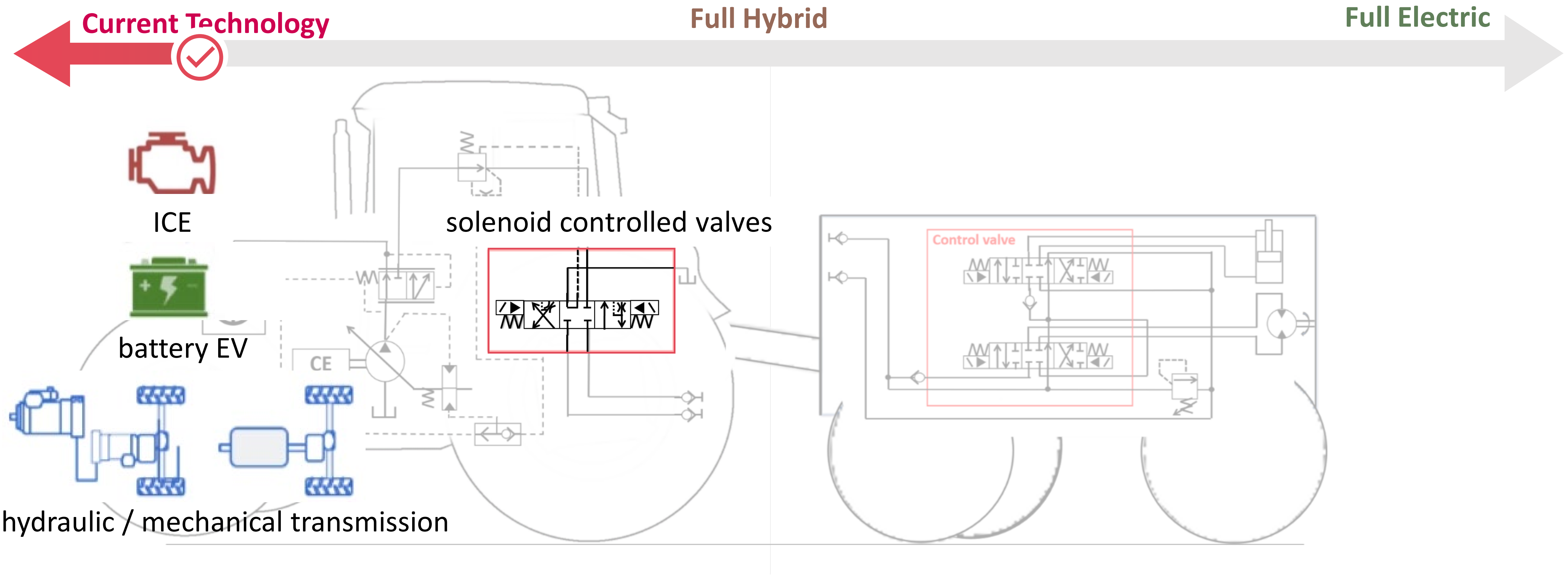
Challenges on Agricultural Machines

Challenges: System efficiency drops to only 18% when connected to the planter.
Better integration between the tractor and implements is required to solve this inefficiency.

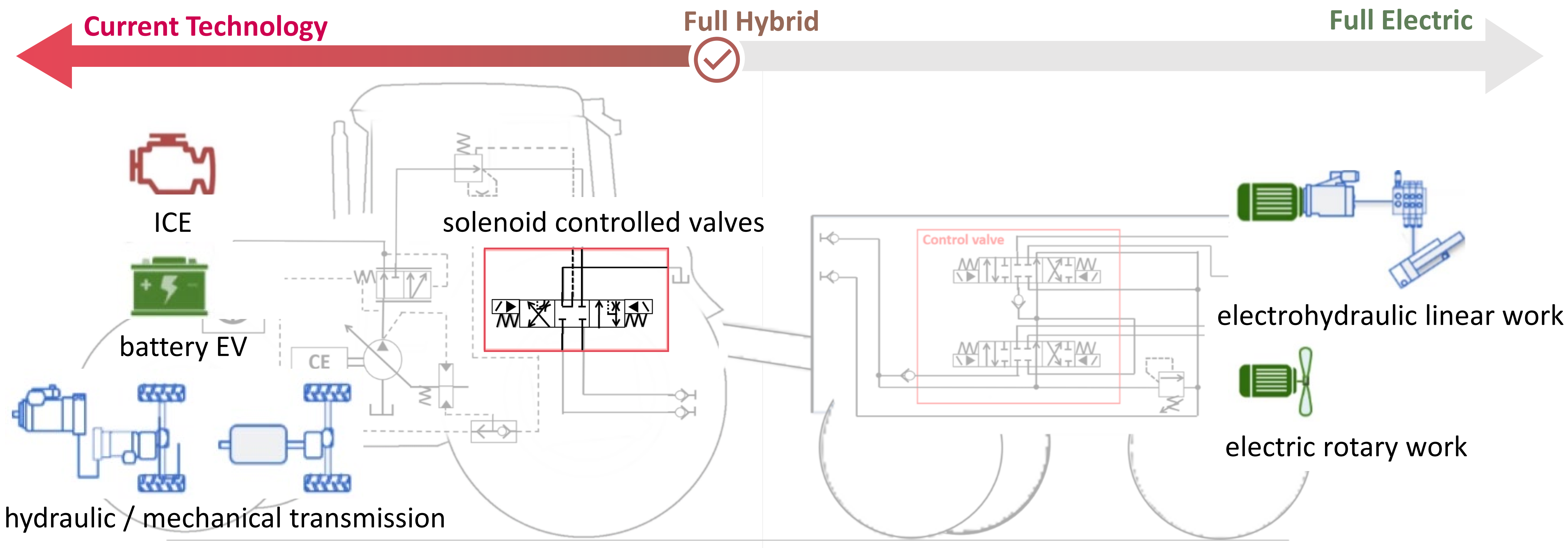


Fully instrumented tractor and planter performing field test @ Purdue Farm

Electromobility Trend



Electromobility Trend



Challenges: Further investigation is needed on the power saving potential from different topologies of tractor auxiliary functions electrification.

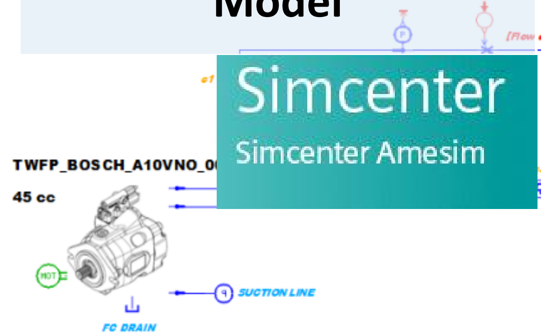
Research Objective and Approach

Objective

To **propose and experimentally demonstrate solutions,** and to **provide insights of partial electrification potential** on the **tractor high-pressure hydraulic circuit** to reduce fuel consumption and possibly lower total cost of ownership for the next generation of green, high-efficient agricultural tractors.

Experimental Characterization

Validated Amesim Model



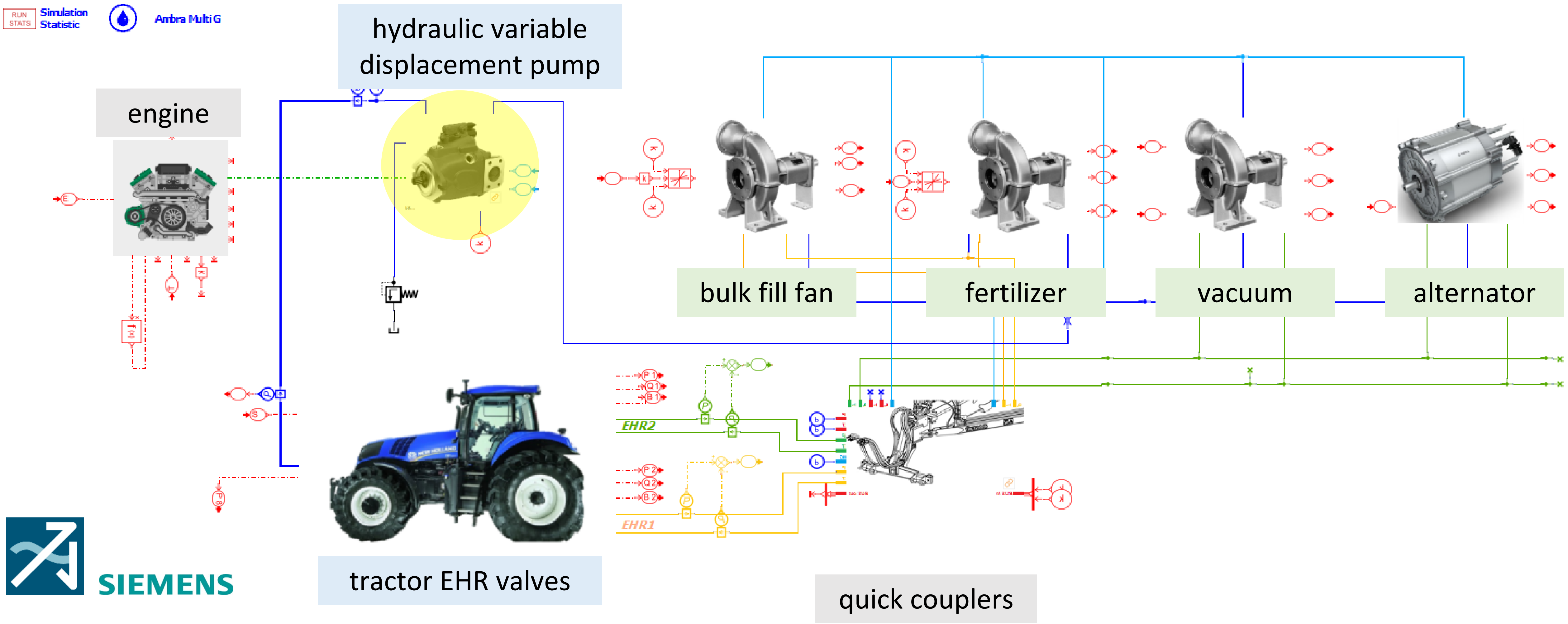
Solution Proposal

Evaluation, Iteration, Improvement

CNH Cash Crop High (CCH) agricultural tractor T.8.390 New Holland

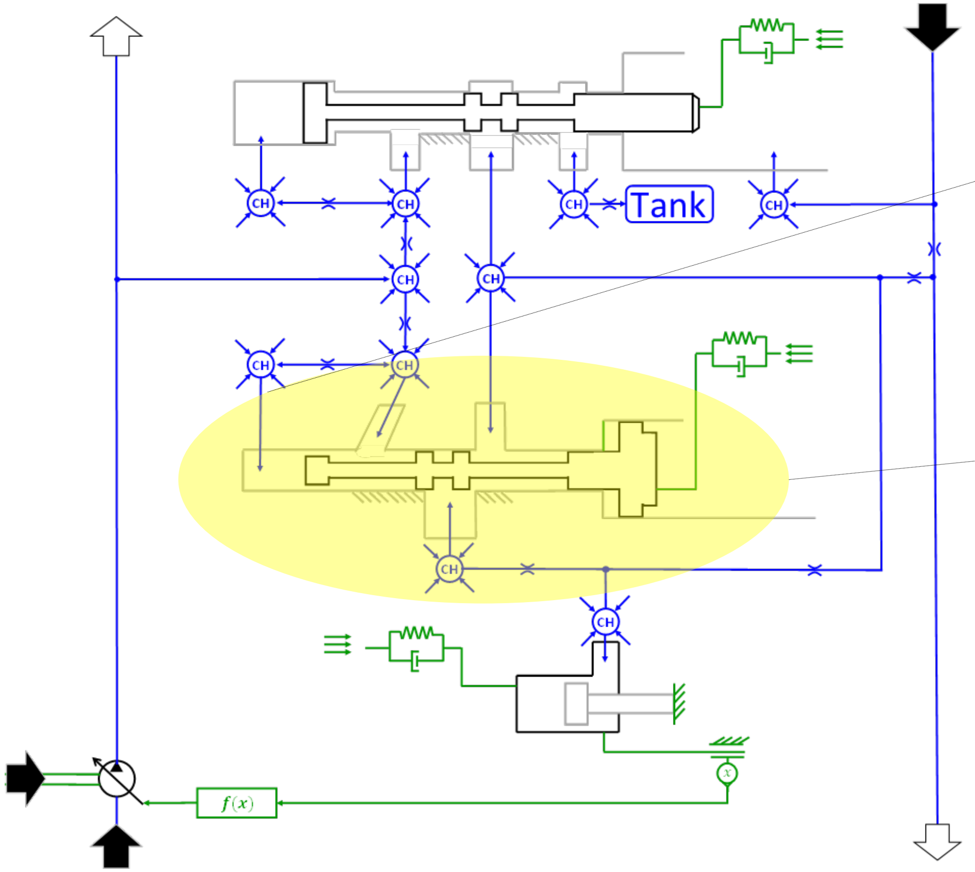
Case IH Early Riser 2150 16 Row Front-Fold Trailing Planter

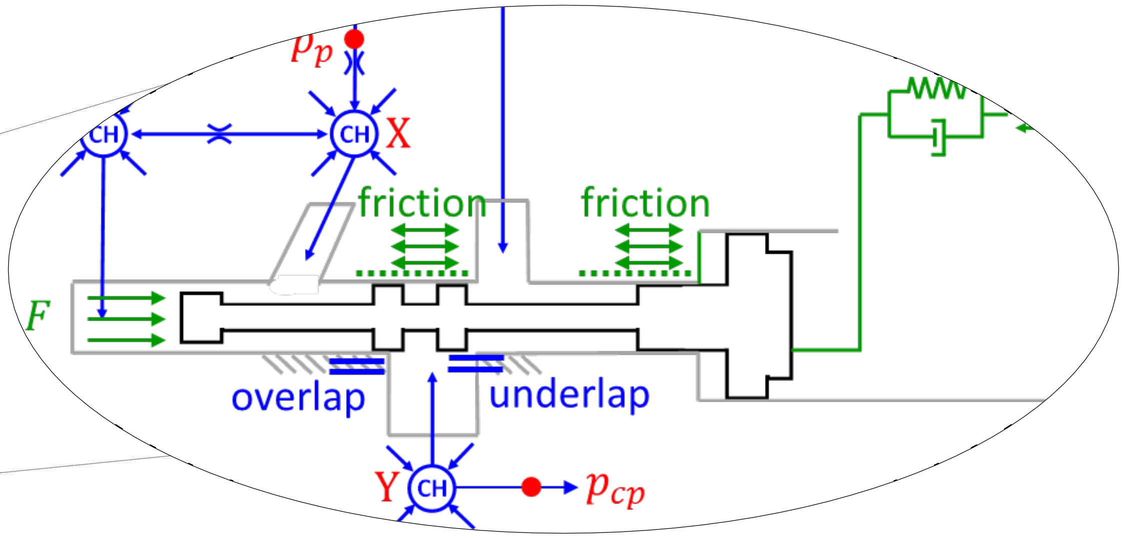
System Model Development



SIEMENS

LS Pump Modeling





pressure compensator

F_s spool equilibrium: $F_{sol} + F_p = F_s + F_{jet} + F_f$

$F_{jeti} = K_i \cdot 2 \cdot c_q \cdot A_i \cdot \Delta p_i \cdot cos\theta \quad i = 1,2$

friction — viscous friction force: $f = -b \cdot v$

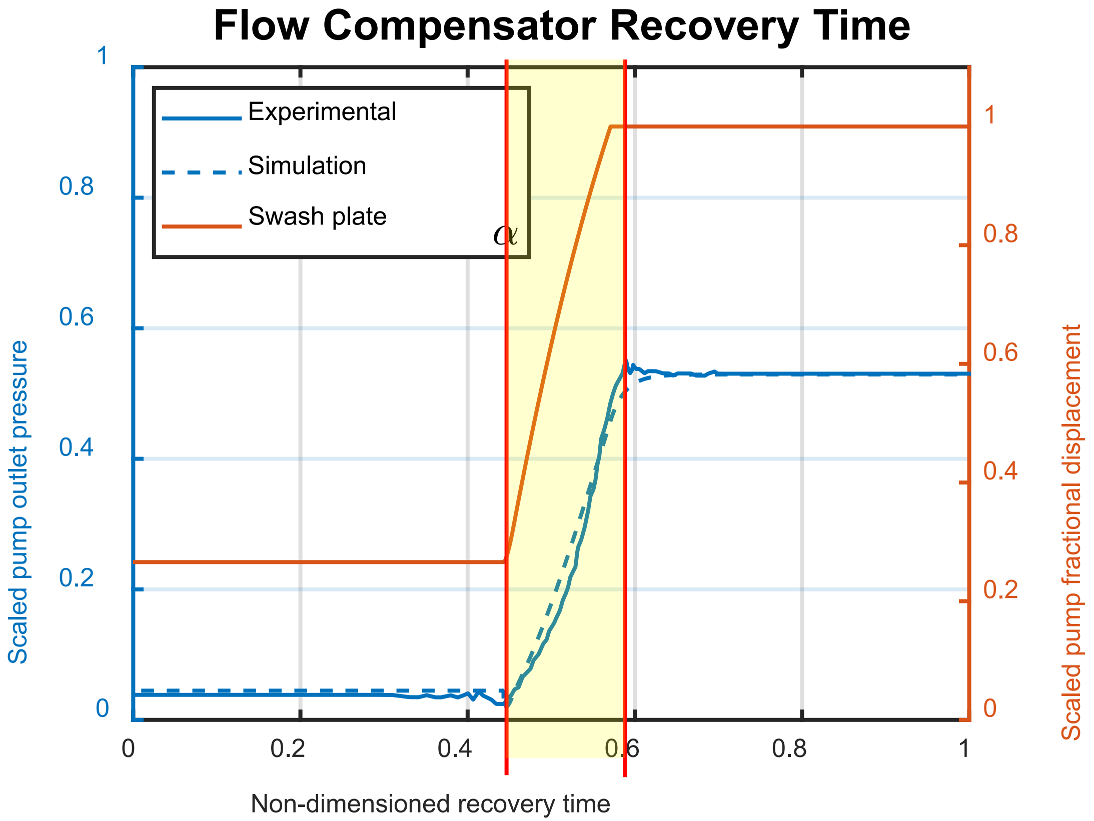
overlap — underlap: $x_{lap} = x_0 + x$

internal volumes: $\frac{dp}{dt} = \frac{B(p) \cdot Q(p)}{V(p)}$

orifice equation: $Q = c_q \cdot A \cdot \sqrt{\frac{2|\Delta p|}{\rho}} \cdot sign(\Delta p)$

orifice area: $A_o = (\theta - sin\theta) \cdot \frac{d_{hole}^2}{8}$

Pump Model Dynamic Performance Validation



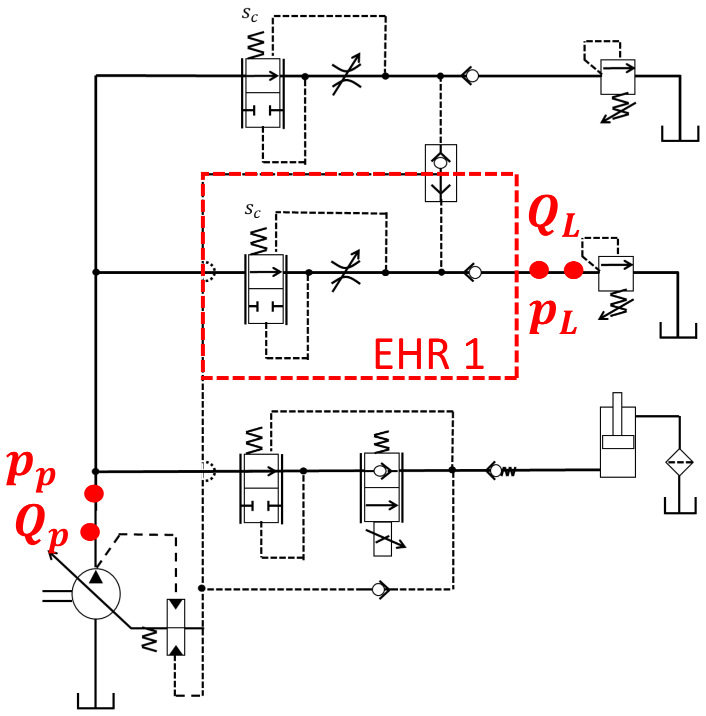
Agreement Between Simulation & Experiments (%)

	Load Pressure	**Deadhead Pressure**	**Response Time**	**Recovery Time**
Pressure Compensator	95.08	99.29	22.25	97.93

	Load Pressure	**Standby Pressure**	**Response Time**	**Recovery Time**
Flow Compensator	99.79	83.22	99.66	97.34

*% agreement=|EXP−SIMUL|/EXP×100%

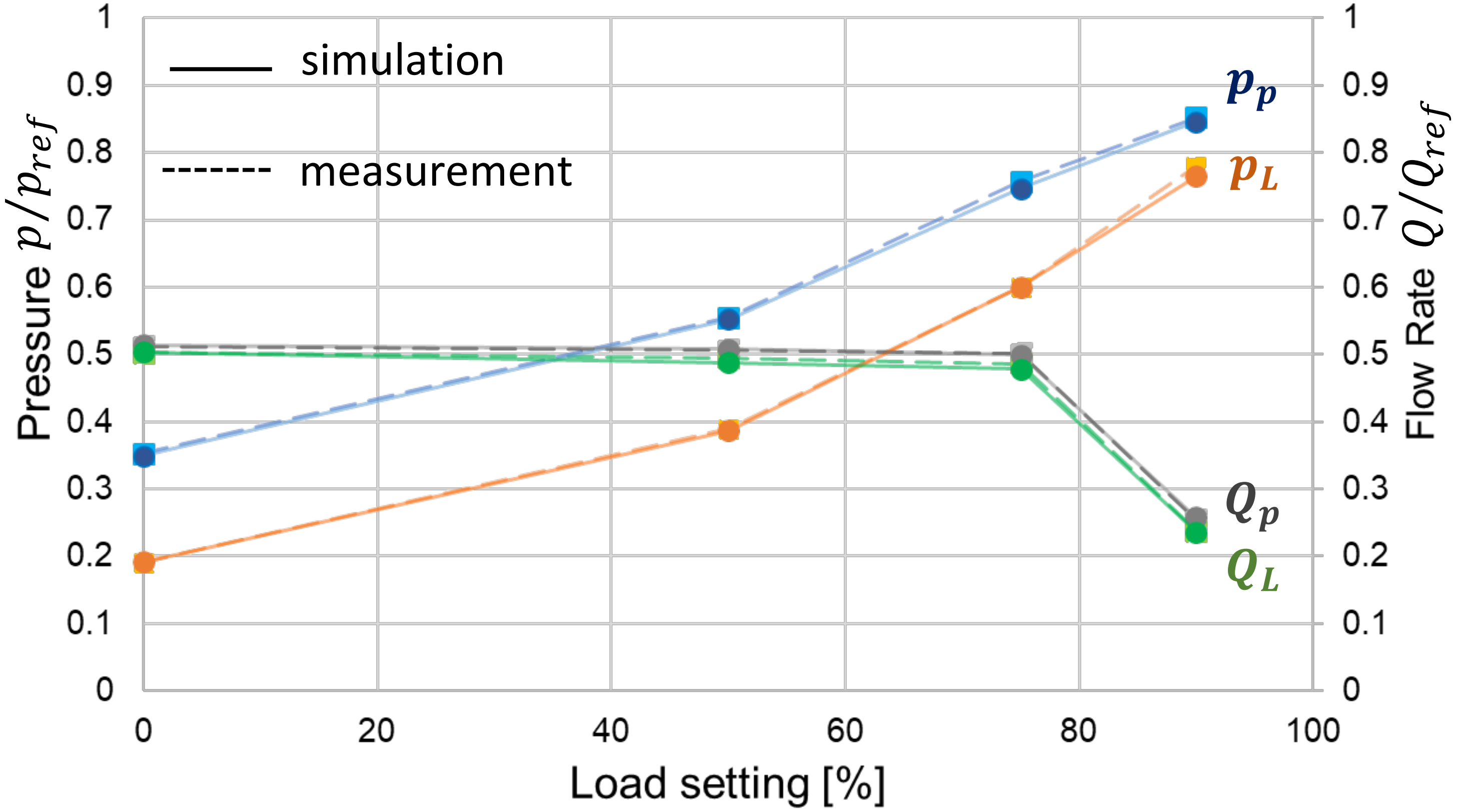
System Model Validation Results



Simplified Supply Circuit with
Dual Remote Control Valves

Single Remote Test Results Comparison

Full command, Retraction, High RPM, High T_{oil}

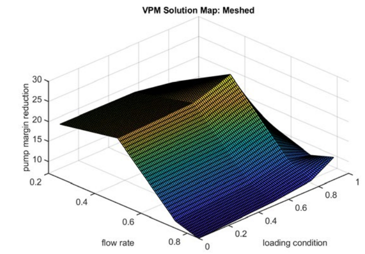


In total 272 remote tests, average agreement over 88% under different conditions.

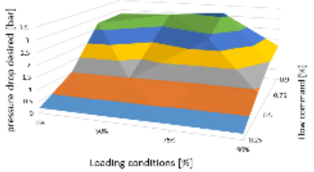
Energy-efficient Solutions

Tractor Solutions

VPM

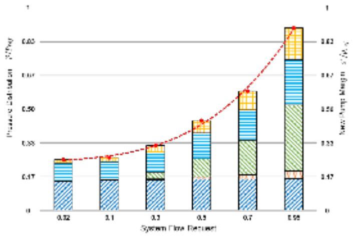


HVM

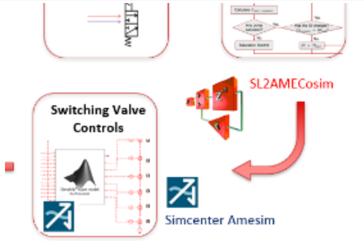


Tractor-Planter Solutions

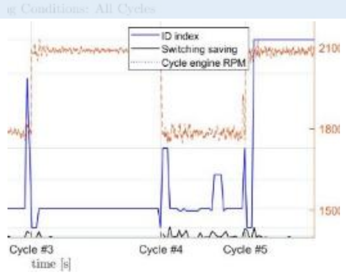
IPSC



DRC

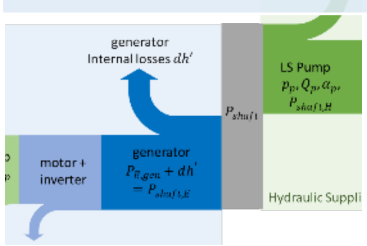


SRC

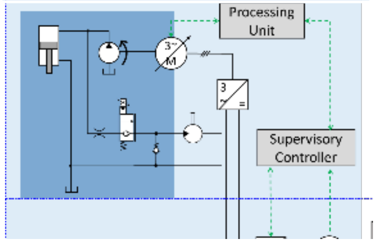


Electrification Solutions

Selective Electrification



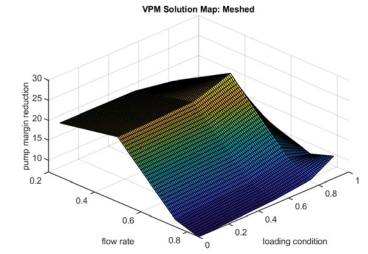
Selective E-pump



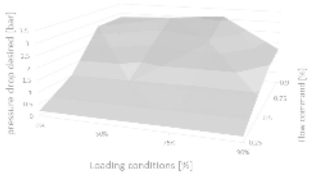
Energy-efficient Solutions

Tractor Solutions

VPM

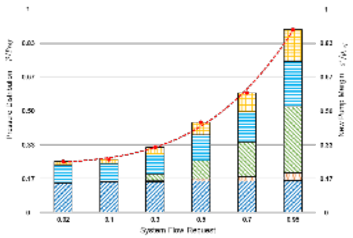


HVM

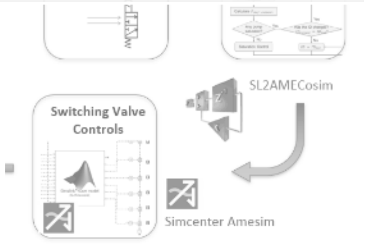


Tractor-Planter Solutions

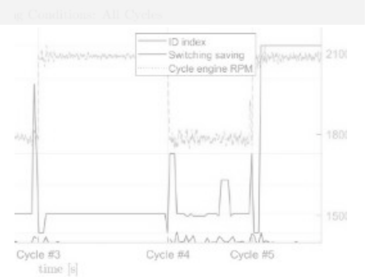
IPSC



DRC

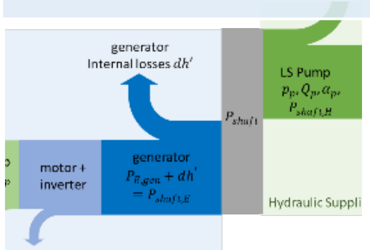


SRC

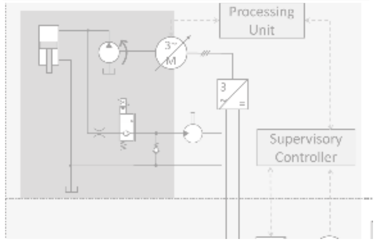


Electrification Solutions

Selective Electrification

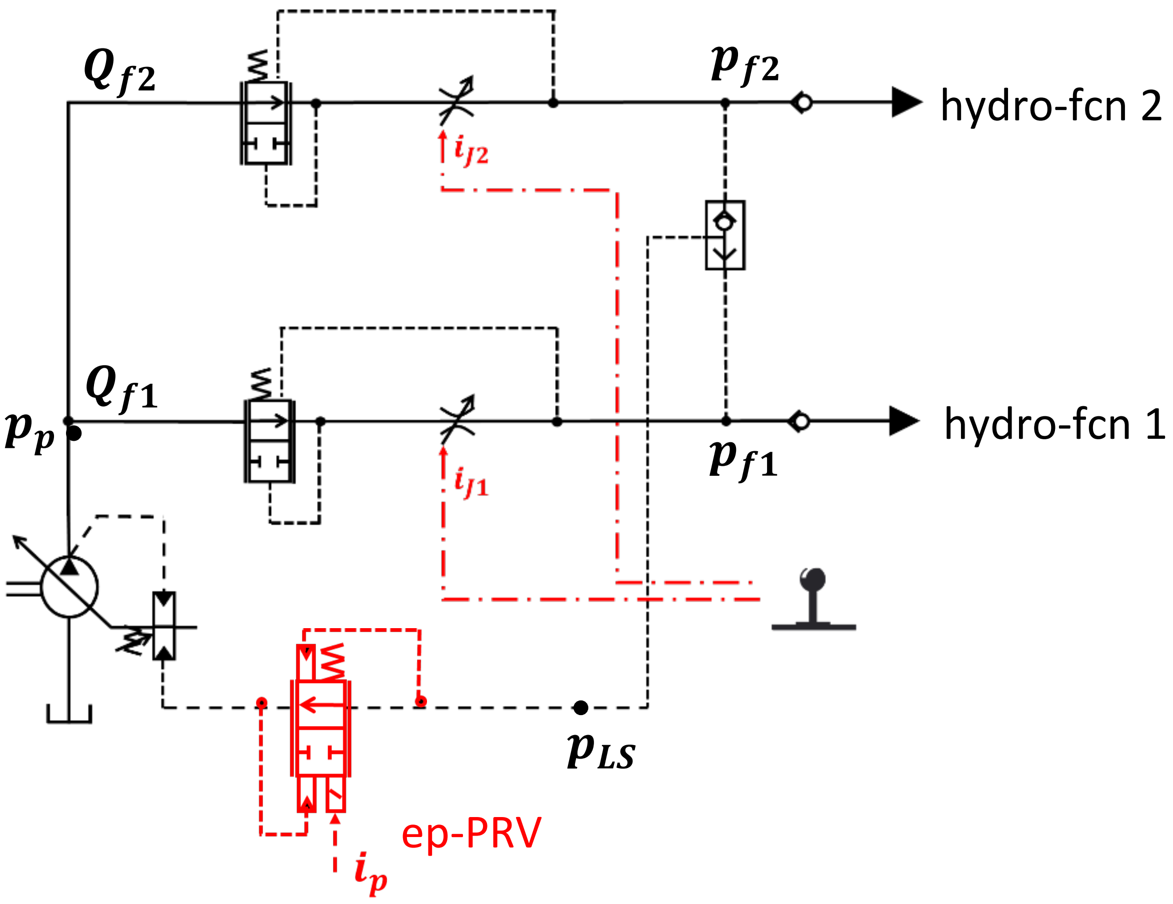


Selective E-pump

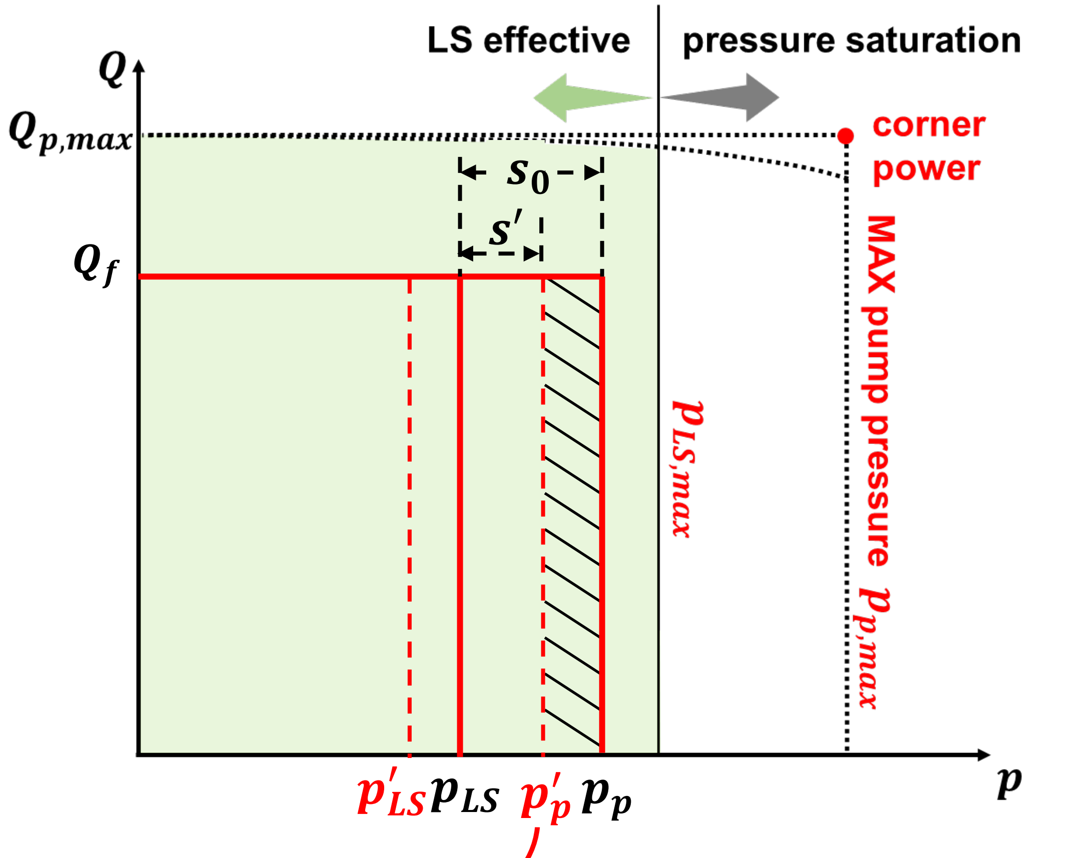


Variable Pump Margin (VPM) Solution

- Reduce the system power requirements by optimally reduce the pump margin setting supplying different loading conditions in time.

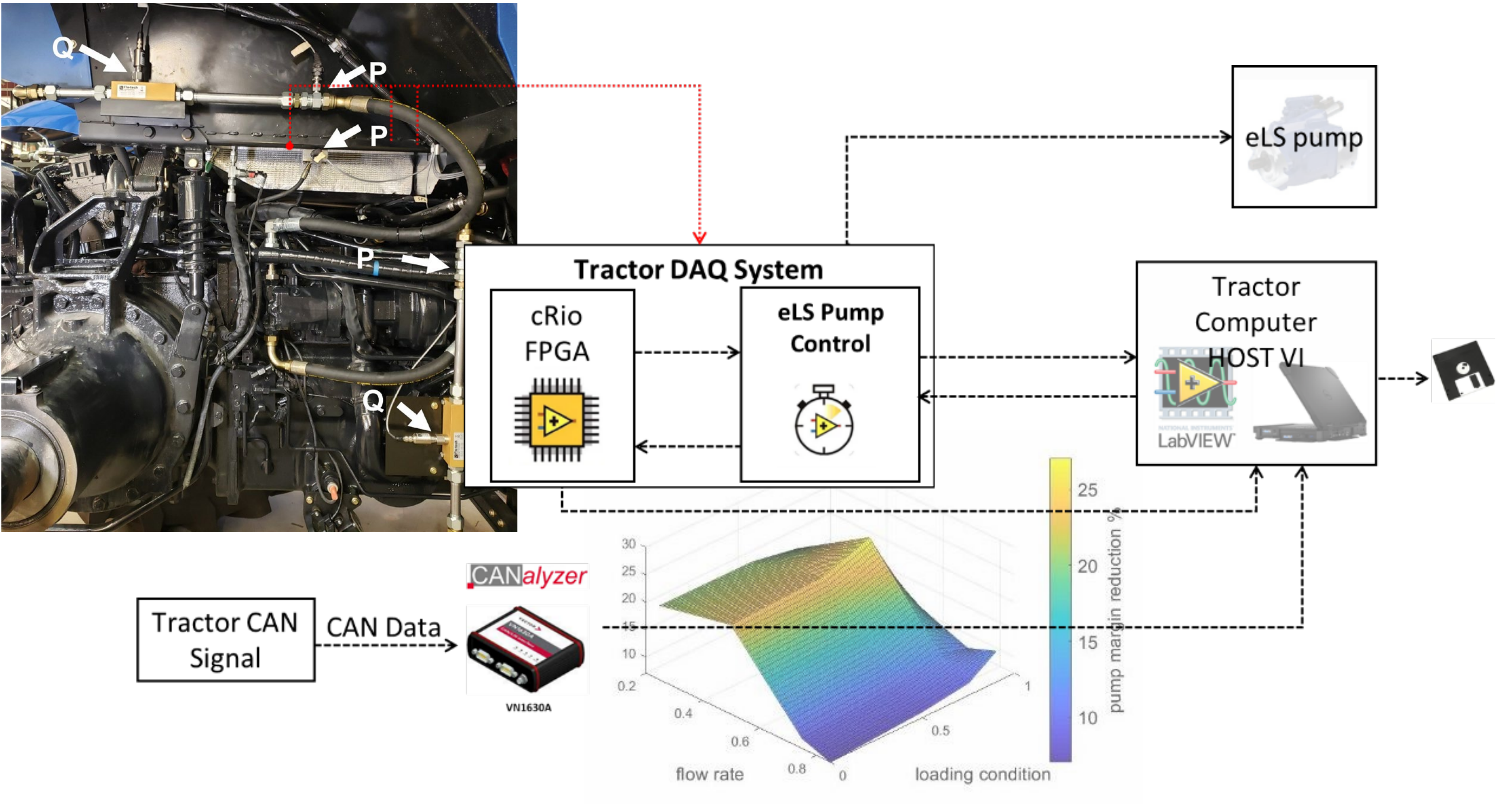


VPM Solution with Simplified Supply Circuit

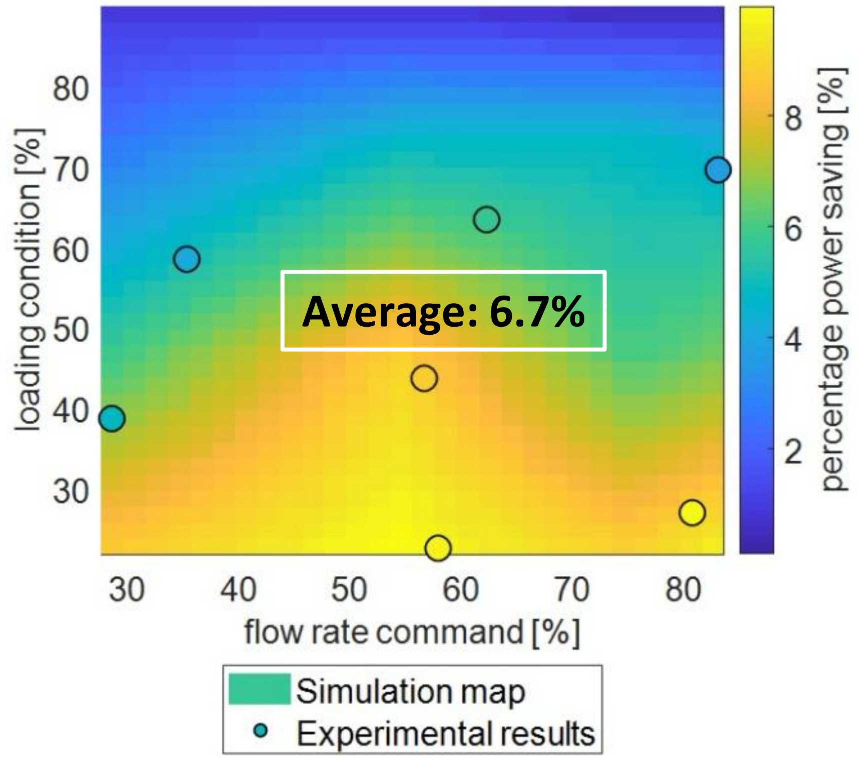


Key: Determine p'_p

VPM Solution Exp Setup and Result

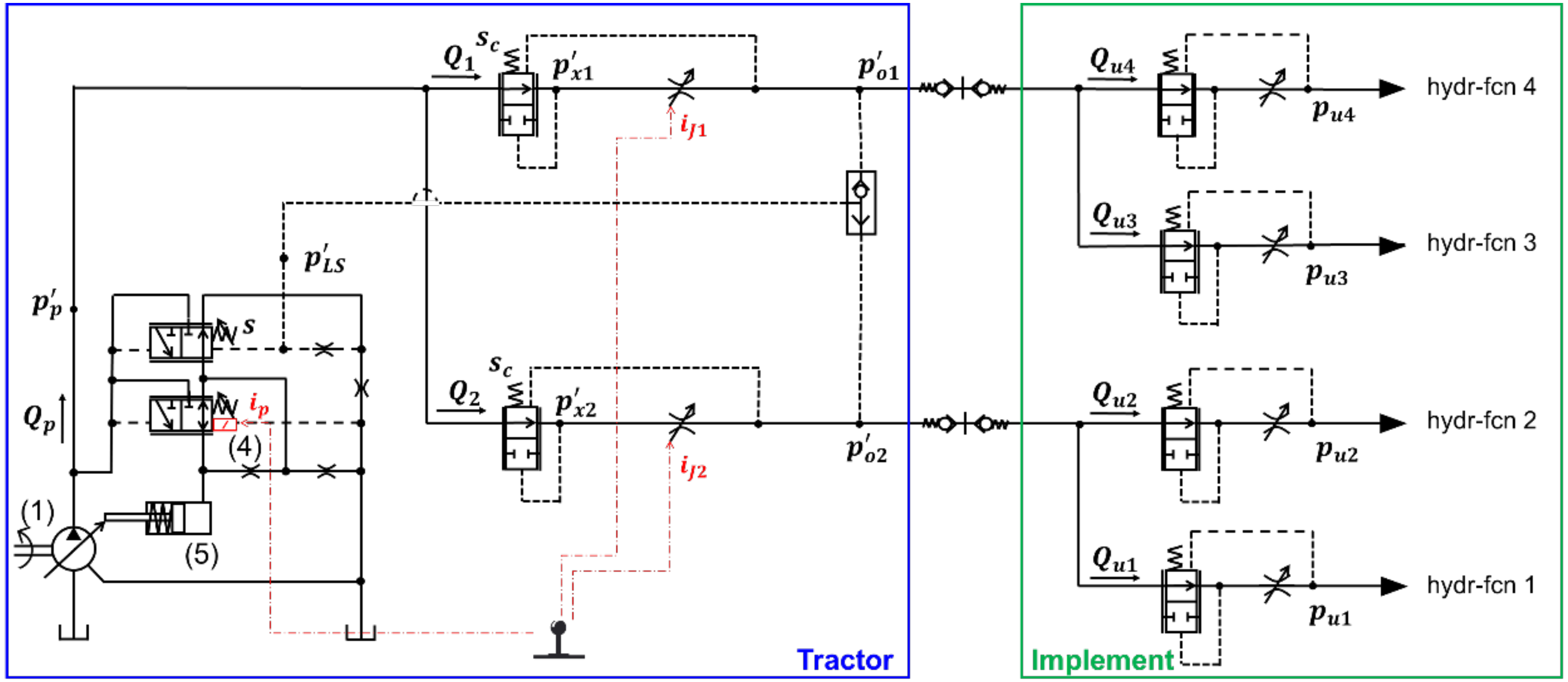


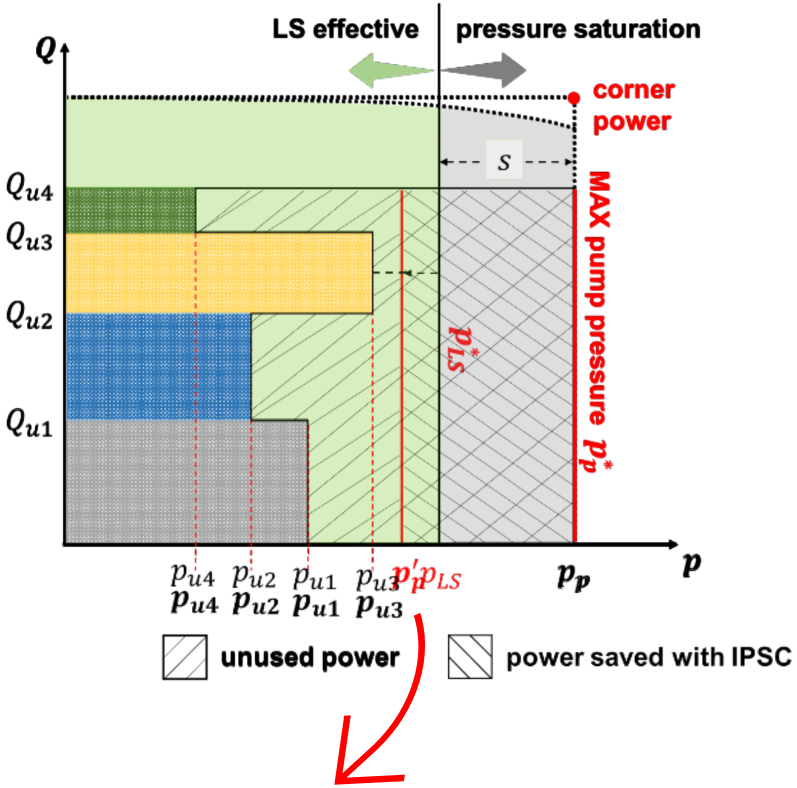
Percentage Power Saving [%]



Intelligent Pressure Saturation Control (IPSC)

- Solve the tractor-planter hydraulic conflicting valve control inefficiency issue by intelligently control the supply pressure levels.

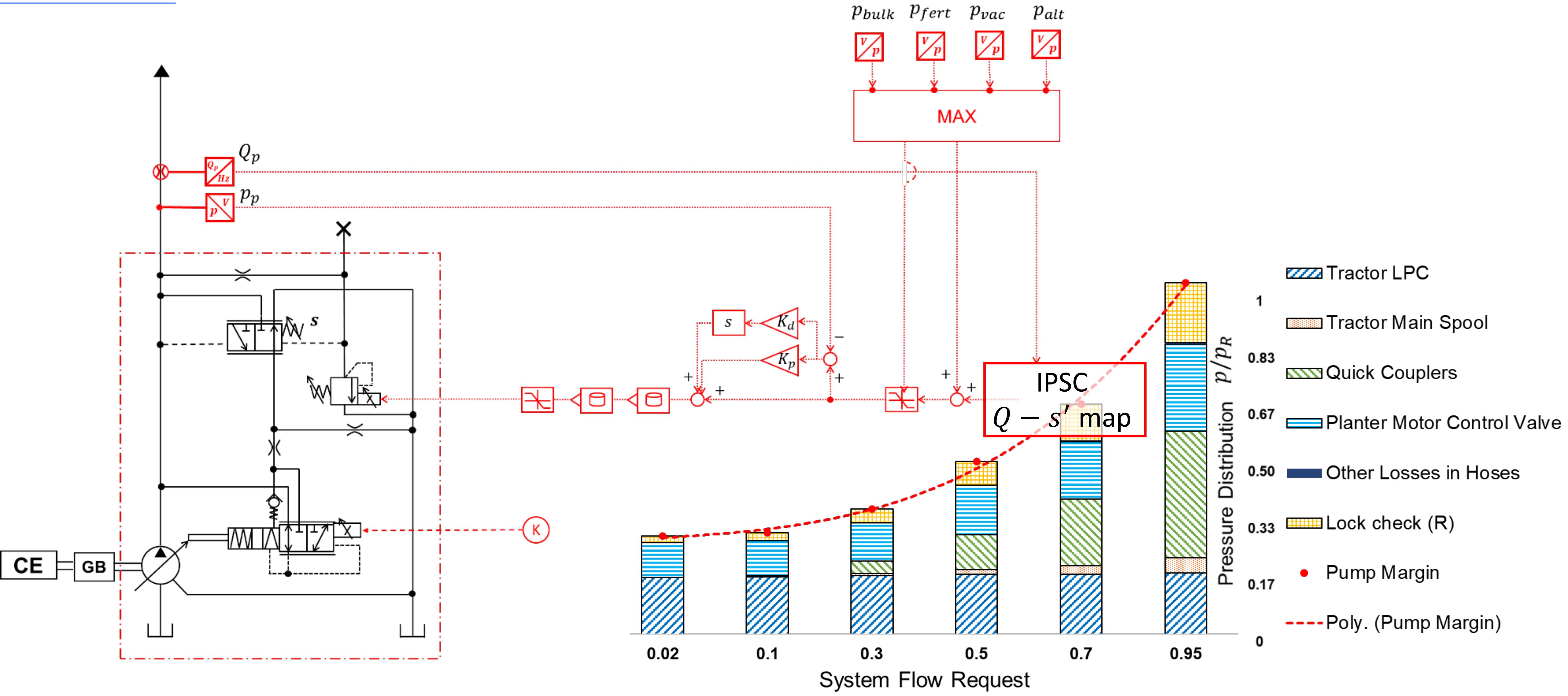




Flow source ⟶ Pressure source

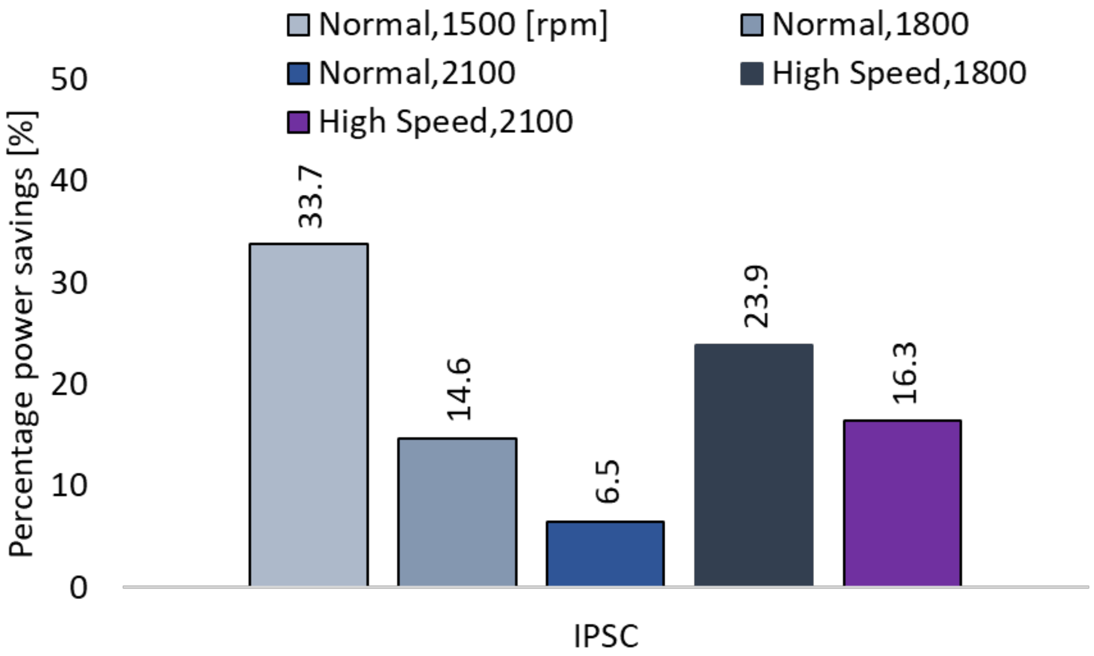
Key: Determine the optimal pump delivery pressure (or s') level under different operating conditions.

IPSC Implementation with ELS Pump



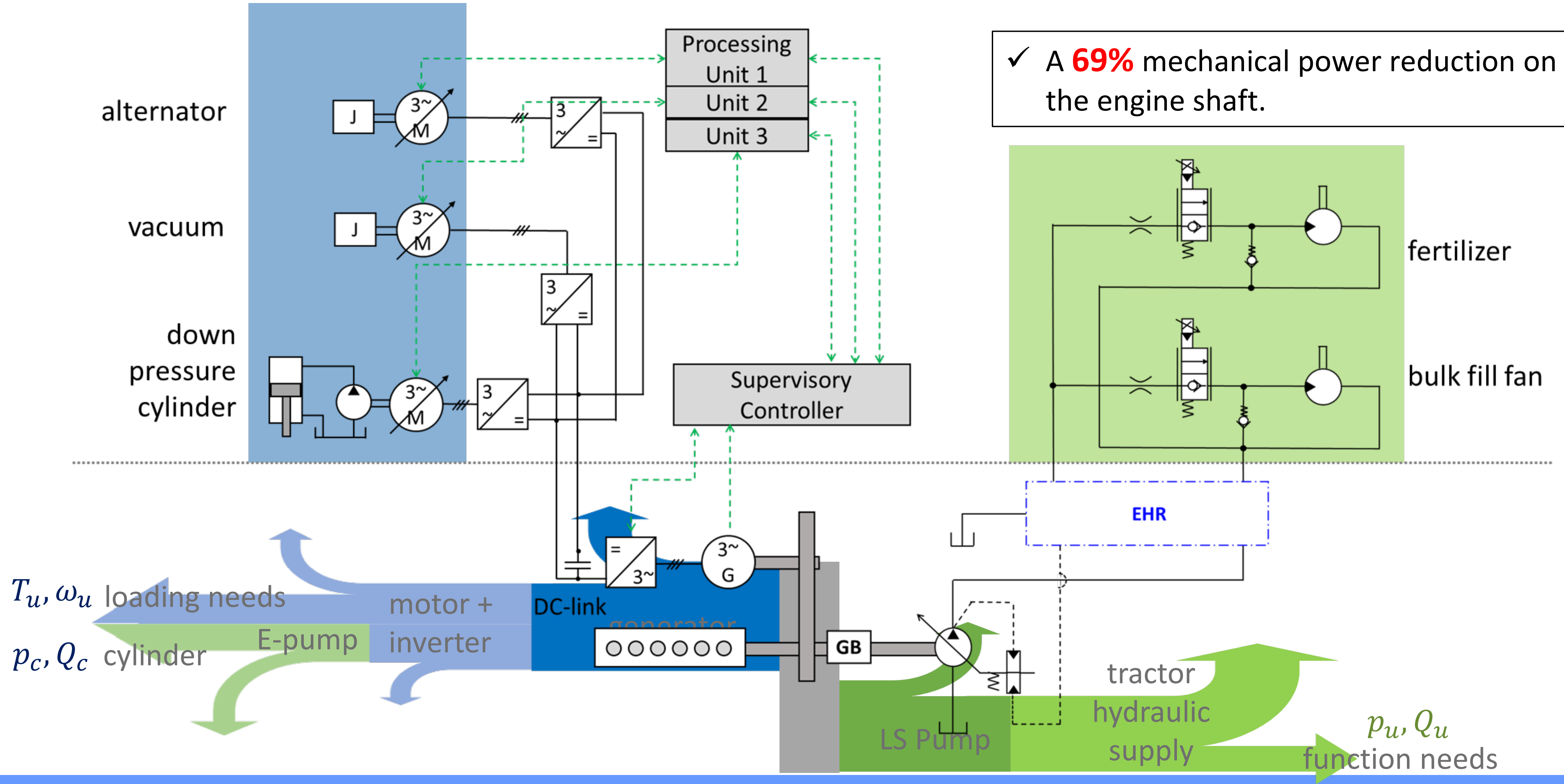
IPSC Field Test Power Saving Results

12 in-lab stationary tests
55 field tests @ Purdue Animal Science Research and Education Center (ASREC)



- ✓ Mechanical power consumption reduction up to 33.7% in the field tests.
- ✓ Fuel rate reduction up to 6.5%.

Electrification Solution - Selective Electrification



✓ A **69%** mechanical power reduction on the engine shaft.

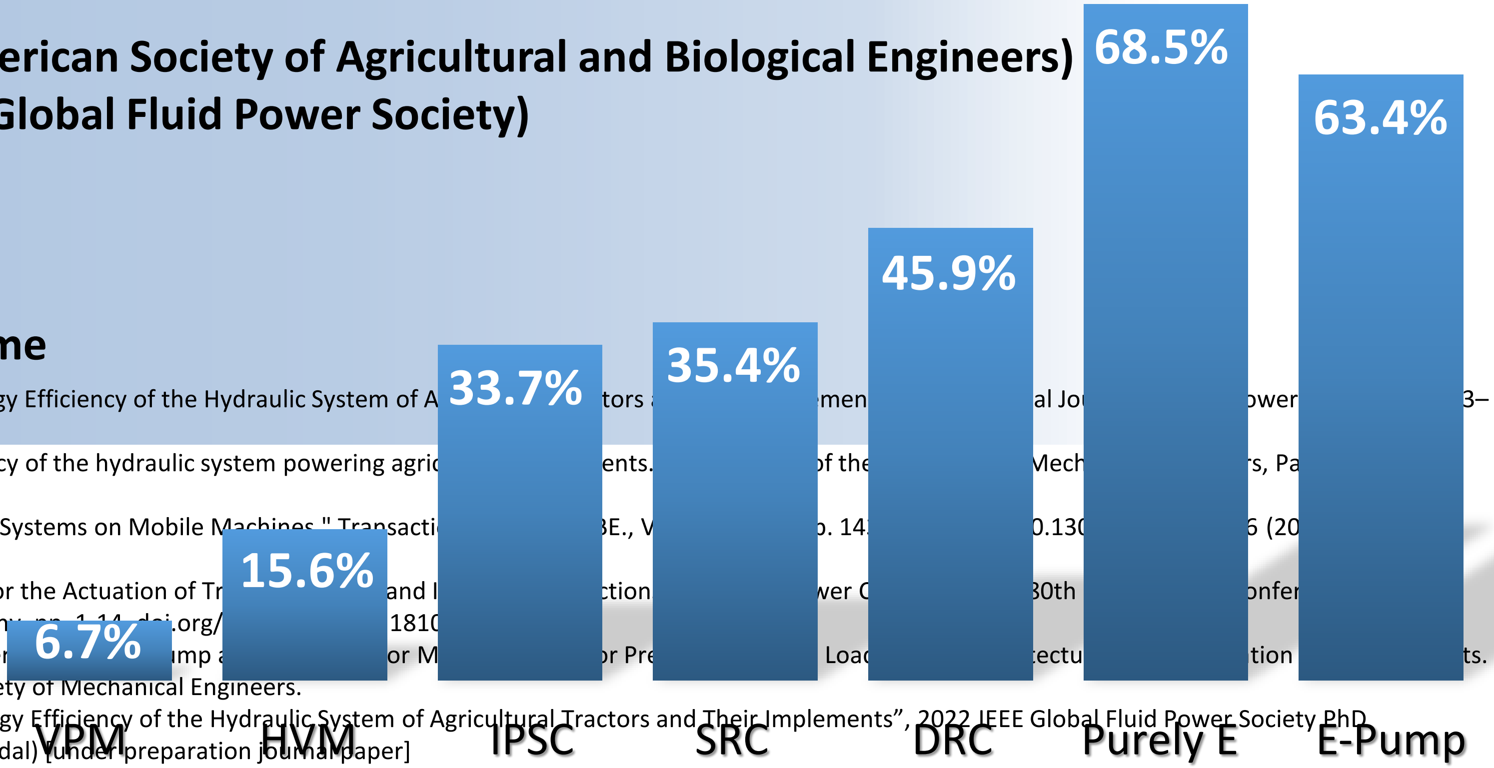
Conclusions and Original Contributions

- Identified the market leading agricultural machines as reference systems.
- Developed and validated the models through lumped-parameter approach.
- Identified the power loss sources.
- Proposed and experimentally/though simulation demonstrated energy-efficient solutions.

Two Best Paper Awards

- **ASABE 2022 Superior Paper Award (American Society of Agricultural and Biological Engineers)**
- **GFPS 2022 Best Paper “Backe" Award (Global Fluid Power Society)**

3 journal publications
5 conference proceedings
4 granted US patents with one more to come



1. **Tian, X.,** et al. 2024, “New Hydraulic Control Technologies for Improving the Energy Efficiency of the Hydraulic System of A tors men al Jo ower 3–224. doi: 10.13052/ijfp1439-9776.2525.
2. **Tian X.,** et al. 2024. “A pressure control method for increasing the energy efficiency of the hydraulic system powering agric ents. of the Mech rs, Pa Systems and Control Engineering. 2024;0(0). doi:10.1177/09596518241227250
3. **Tian, X.,** et al., 2021, "Power Saving Solutions for Pre-Compensated Load-Sensing Systems on Mobile Machines," Transacti BE., V p. 14 0.130 6 (20 Superior Paper Award) [American Society of Agricultural and Biological Engineers]
4. **Tian, X**., et al. 2023, "An Analysis of Mixed Hydraulic and Electric Configurations for the Actuation of Tr and I ction wer C 30th onfer Agricultural Engineering Land.Technik AgEng, Nov 10-11, 2023, Hannover, German doi.org/ 1810
5. Stump, P.**, Tian, X**., Lengacher, J., Jenkins, R., Vacca, A., & Fiorati, S. (2023, October ump a or M r Pre Load ectu tion ts. In Fluid Power Systems Technology (Vol. 87431, p. V001T01A071). American Society of Mechanical Engineers.
6. **Tian, X.,** et al., 2022, “New Hydraulic Control Technologies for Improving the Energy Efficiency of the Hydraulic System of Agricultural Tractors and Their Implements”, 2022 IEEE Global Fluid Power Society PhD Symposium (GFPS 2022), Oct. 12-14, Naples, Italy. (Best Paper Award "Backe" Medal) [under preparation journal paper]
7. **Tian, X**., et al. 2019, “Analysis of Power Distribution in the Hydraulic Remote System of Agricultural Tractors Through Modelling and Simulations”. ASME/BATH 2019 Symposium on Fluid Power and Motion Control. American Society of Mechanical Engineers Digital Collection. Oct 7-9, 2019, Sarasota, FL, USA.
8. **Tian, X**., et al. 2019, "An Analysis of the Energy Consumption in the High-Pressure System of an Agricultural Tractor through Modeling and Experiment", 77th International Conference on Agricultural Engineering Land.Technik AgEng, Nov 8-9, 2019, Hannover, Germany, pp. 9-18. doi.org/10.51202/9783181023617
9. Pintore, F., Fiorati, S., Vacca, A. and **Tian, X**., CNH Industrial America LLC, 2023. System and method for controlling hydraulic pump operation within a work vehicle. U.S. Patent 11,834,811.

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Thanks for your attention!

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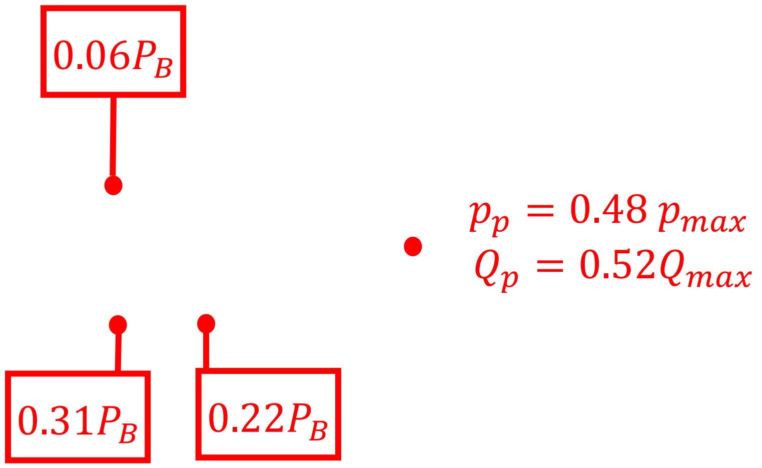
CNH PURDUE UNIVERSITY Maha Fluid Power RESEARCH CENTER



$0.06P_B$
$p_p = 0.48\, p_{max}$
$Q_p = 0.52 Q_{max}$
$0.31P_B$
$0.22P_B$