CHANGING WHAT'S POSSIBLE

Transformer-less Unified Power Flow Controller for Wind and Solar Power Transmission

Presenter(s): Fang Z. Peng, and Shuitao Yang

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Project Objectives

Overall Goals

- To develop and demonstrate a transformer-less UPFC

Uniqueness

- Unique Topology: cascaded multi-level inverters to eliminate transformers
- Scalability and modularity: the same basic blocks to reach any power levels

Challenges

- To achieve superior power flow control for the entire range
- To eliminate active power flow to CMIs and maintain DC voltage

Problems of the Traditional Technology

- Back-to-back inverters required
- No back-to-back connection possible for CMIs

Performance Metrics

- Low cost ($0.05/VA), light weight (1000 lbs/MVA)
- High efficiency (>99%) and fast dynamic response (<5 ms)

Key Outcomes

A working prototype of a 2-MVA transformer-less UPFC system

3rd Year Accomplishments

Q9: ► UPFC functionality test at low voltage level (4,160 V)

► System modulation, control and protection software developed

► 15-kV lab design, and construction

Q10: ► UPFC installation to the 15-kV high voltage lab

Q11: ► System for 13.8-kV/2 MVA UPFC demonstration configured

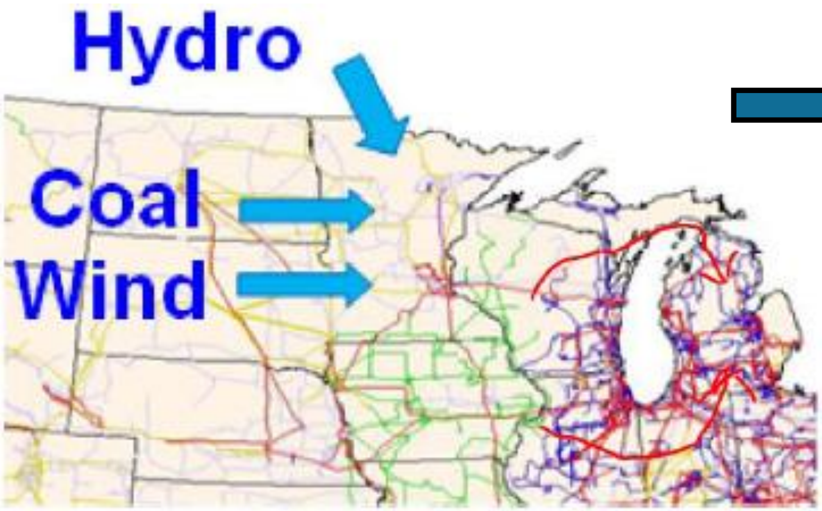
► Functional test with all shunt and series CMI sub-modules

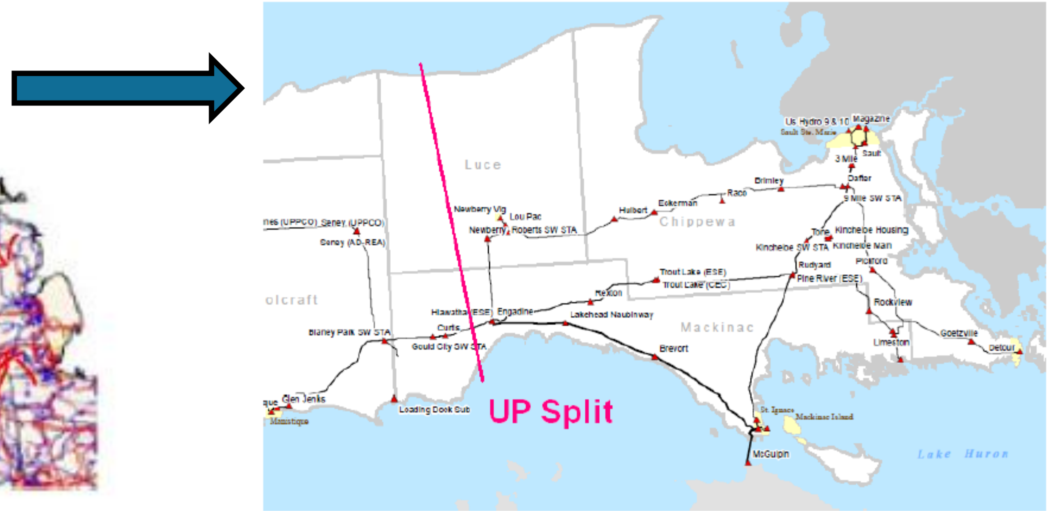
Q12: ► Initial UPFC test results at 13.8-kV, independent P/Q control and dc

voltage balancing control implemented

► Testing data collected and analyzed

Michigan UP Grid Scenario

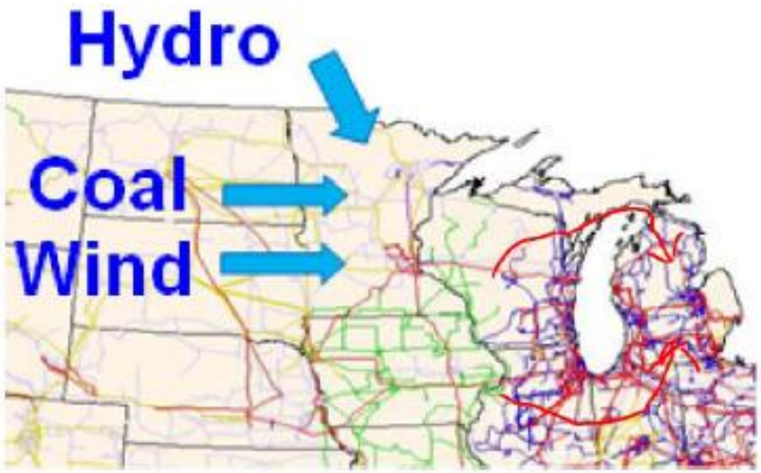


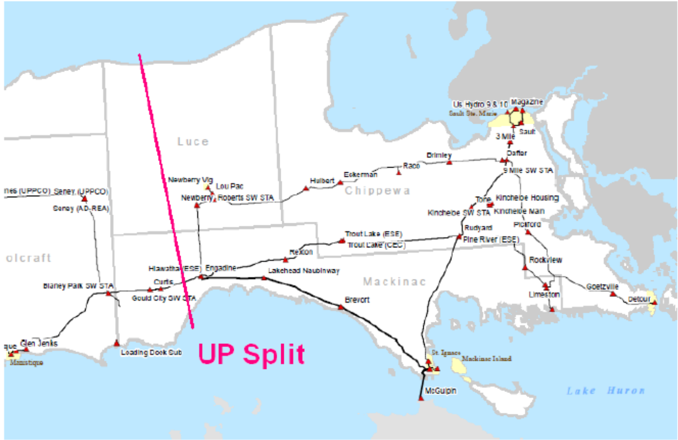


- Loop flow problem: Power demand is high on south and east side of Lake Michigan. But, some power finds its way through high impedance path in the UP.
- Eastern UP grid is "split" from that of West UP in order to prevent overloading of lines/equipment and to eliminate under voltage. UP split is necessary for 95% time of a year.
- Difficult to perform scheduled maintenance, to regulate voltage in eastern UP
- LP disconnected from UP due to high phase shifting requirement

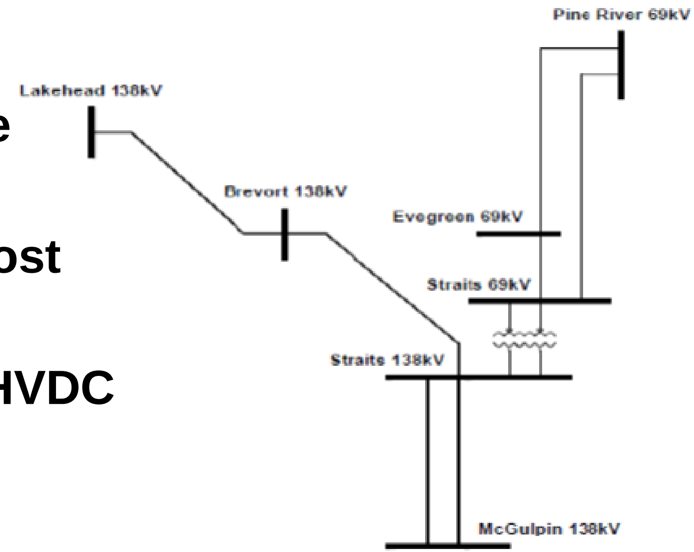
Sankar, et. al, "ATC'S MACKINAC BACK-TO-BACK HVDC PROJECT:PLANNING AND OPERATION CONSIDERATIONS FOR MICHIGAN'S EASTERN UPPER AND NORTHERN LOWER PENINSULAS", CIGRE' 2013 Grid of the future Symposium

Michigan UP Grid Solutions **Investigated**





- **Building new lines. New lines could not solve the problem, other measures (power flow control) were needed.**
- **Back-to-back HVDC intertie of west and east UP: cost prohibited, rejected by the committee**
- **Limited solution: Connecting UP and LP through HVDC to implement partial power flow control**
- **No UPFC solutions have been investigated**



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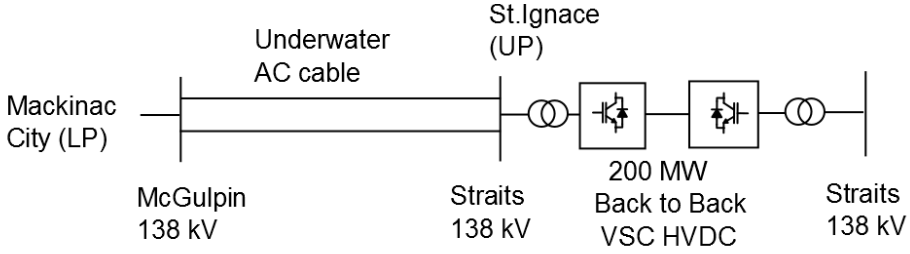
Michigan UP Grid Solutions

Currently used Solution:
HVDC to tie UP and LP



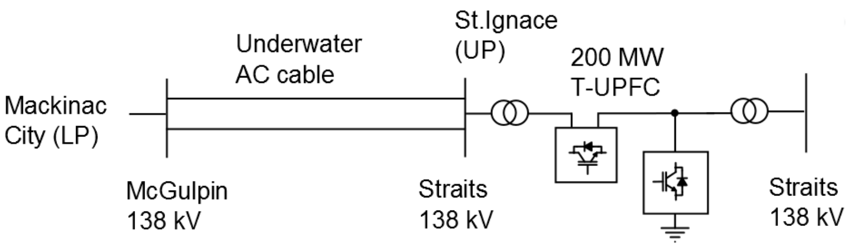
Back-to-Back MMC-VSC
Device Power Rating = 4 pu

4x System Rating

- **Full control over power flow (200MVA/100Mvar)**
- **Cost of power converter = $90 Million** !**
- **Cost of overall project = $130 Million* !**

*St. Ignace news report,** ABB Press Release

Proposed
Solution 1: UPFC to the optimal site
Solution 2: UPFC to tie UP and LP



Cascade Multilevel Inverter (CMI)
Device Power Rating = 0.5-1 pu
For ±30º or 60º phase shifting

(0.5-1)x System Rating
8x smaller device

- **Full control over power flow (200MVA/100Mvar)**
- **Cost of Power Converter = $11-22M ?**
- **Cost of overall project = ?**

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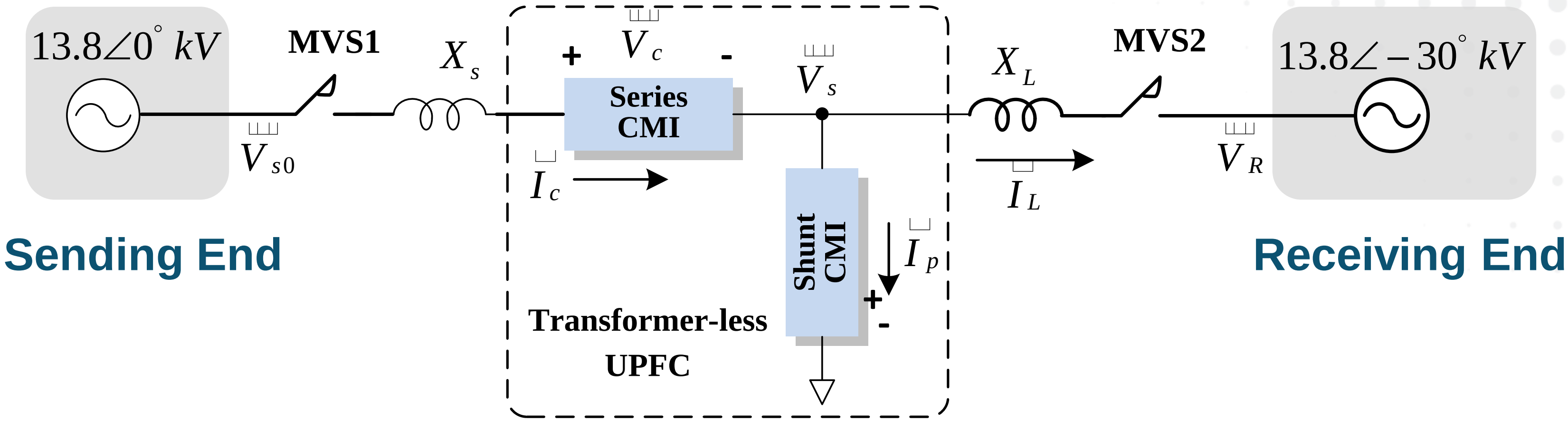
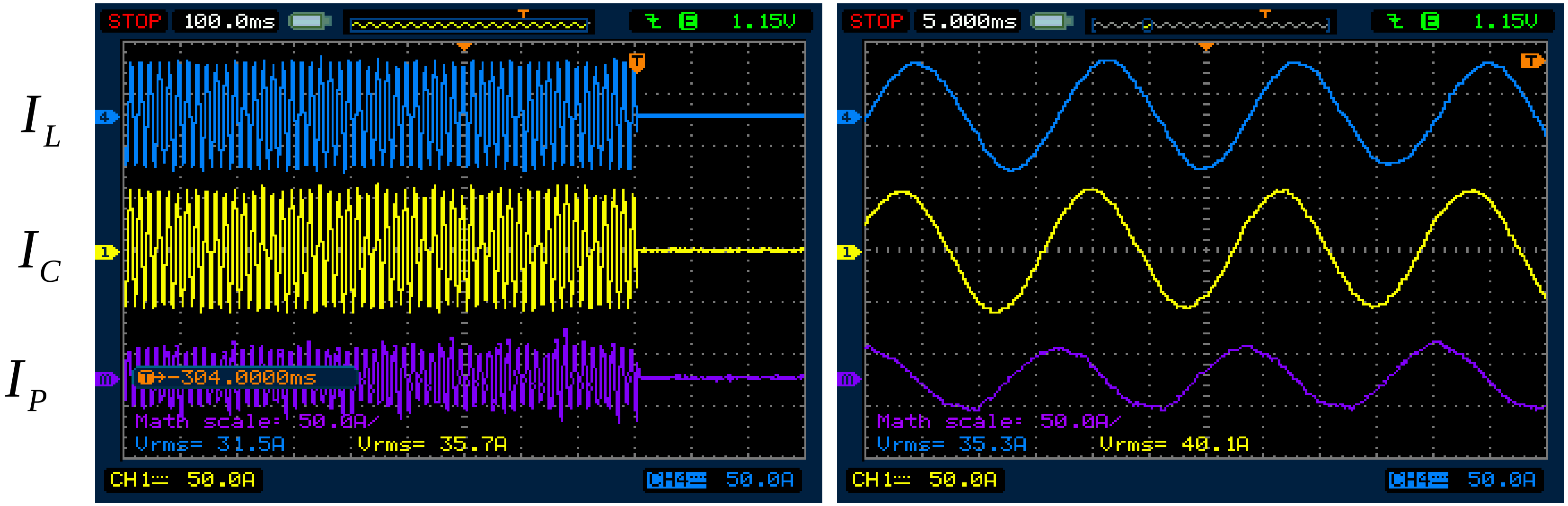
2 MVA **DEMONSTRATION**

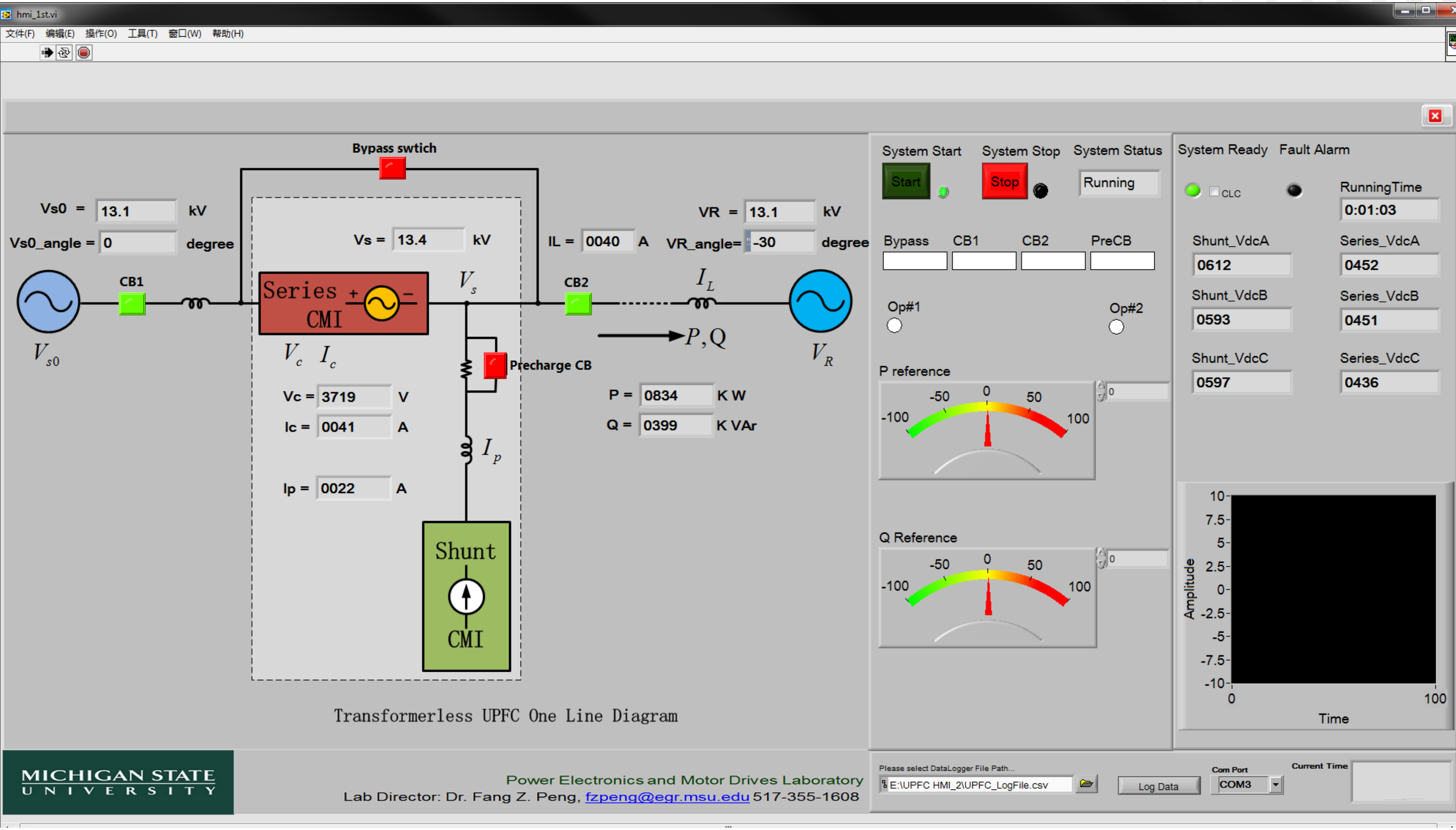
UPFC Test Results at 13.8 kV





13.8 kV UPFC Test Setup and Experimental Waveforms

UPFC Test Results at 13.8 kV



Power angle difference was reduced from the original 30° to 7°

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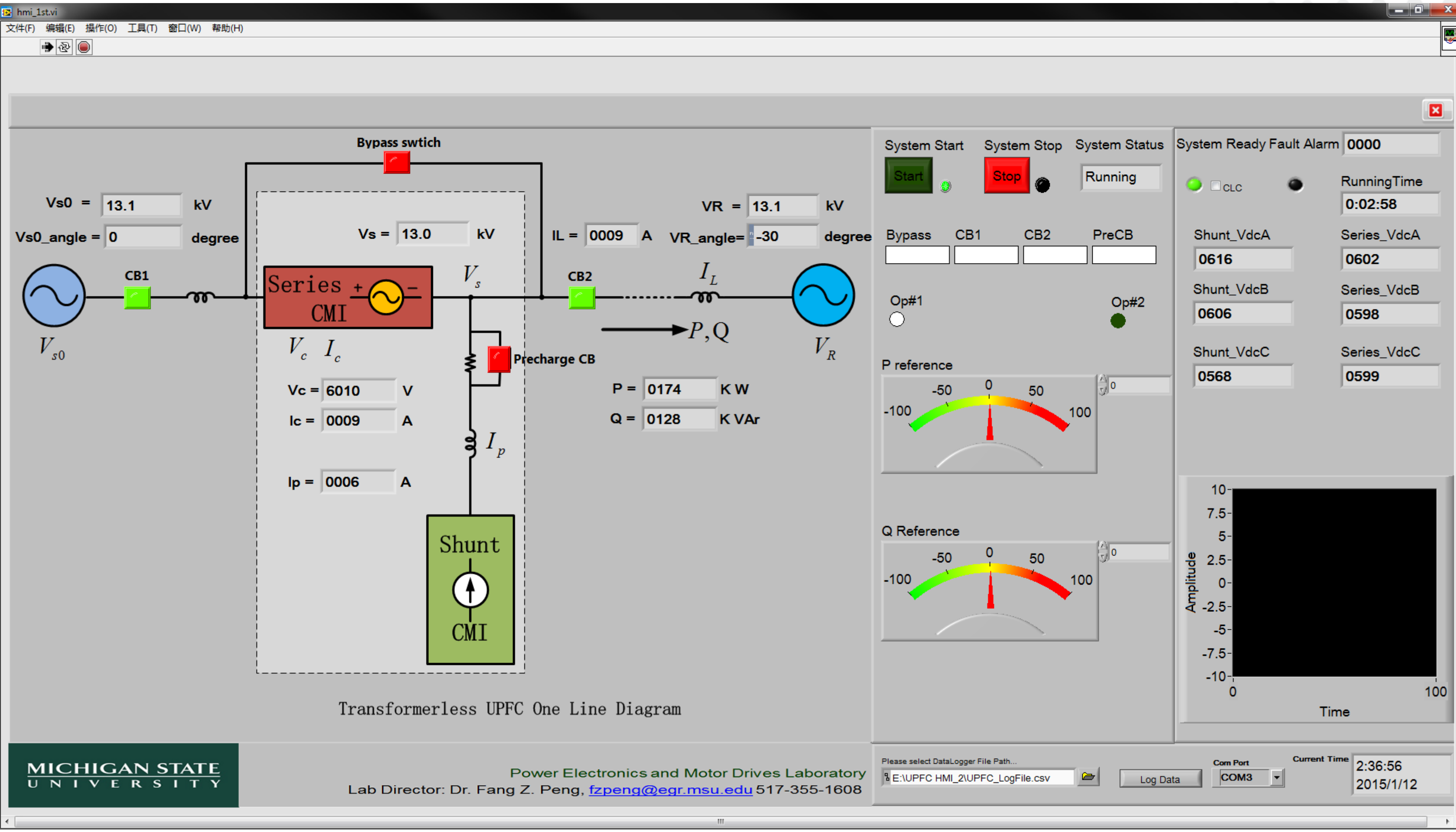
UPFC Test Results at 13.8 kV



Power angle difference was reduced from the original 30° to 2°

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Challenges and New Findings

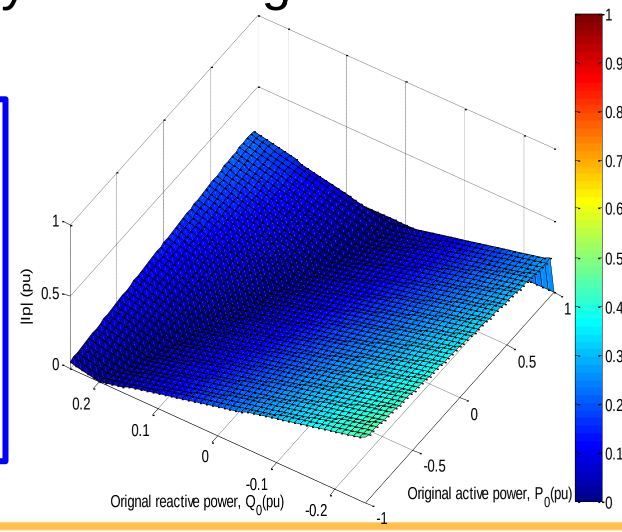
Key Challenges Remaining:

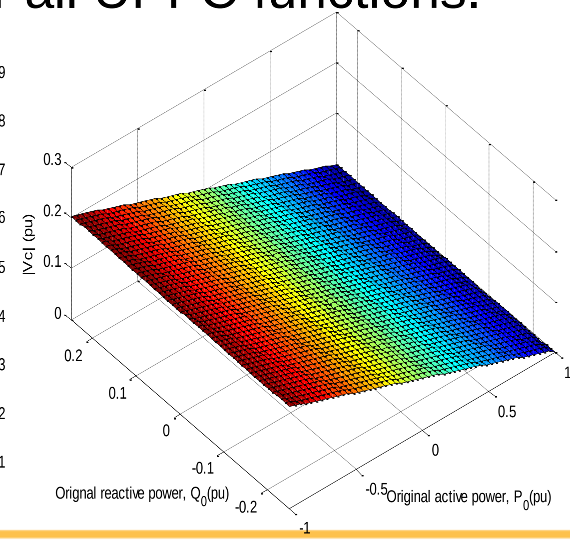
- Pilot test/ demonstration of the UPFC at 15-kV level and 2 MVA rating
- System reliability, bypass and line fault protection

New Findings:

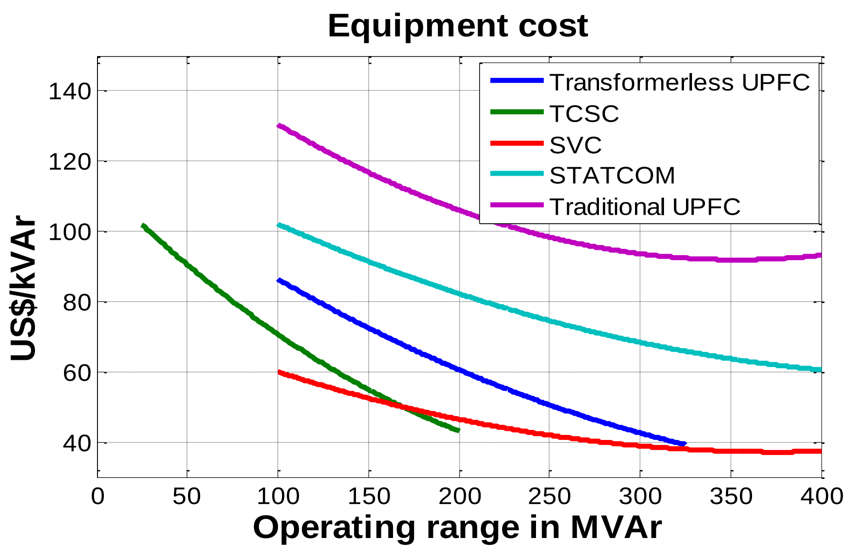
- DC capacitor energy of each CMI to increase network inertia.
- Only a fraction of the system rating is needed for all UPFC functions.

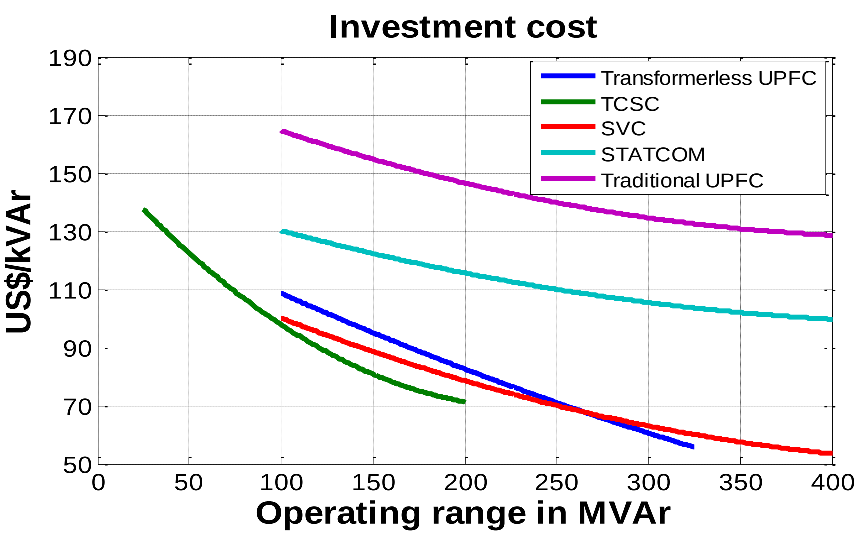
The maximum voltage, $V_{c,max}$ in the series CMIs and the maximum current, $I_{p,max}$ in the shunt CMIs are **0.2** and **0.4** pu, respectively.





Cost Benefit Studies





- On **the IEEE 300 Bus system**, the optimal placements and parameters are:

No. of years	Location	UPFC (pu)	Invest (M)	Benefit (M)
1	121-119	0.138	$0.555	$11.14
5	**191-225**	**1.595**	**$6.382**	**$79.91**
10	191-225	1.595	$6.382	$166.2

SUBSEQUENT INVESTMENT STUDY (5 YEAR BASE)

Investment Period	Location	UPFC (pu)	Invest (M)	Benefit (M)
1	191-225	1.5954	$6.382	$79.91
2	121-119	0.1187	$0.474	$66.63
3	242-245	0.0101	$0.04	$10.13

Near-term Plans

Key commercial challenges to date:

- Uncertain capital funding flow to sustain product development efforts beyond ARPA-E.
- Strong inertia and risk-averse culture of power industry (i.e. utility and vendors-alike).
- Securing real-world demonstration partners for technology.

Upcoming commercial activities:

- Currently talking to a couple of interested companies to explore a pilot project.
- Talking to investors to set up a startup.

Post ARPA-E Goals

- **Immediate Post-ARPA-E plan**
  - Upgrade of prototype to a product
  - Validation of all protection functions to demonstrate reliability
  - Technology transfer of the Transformer-less UPFC
  - Demonstration of the Transformer-less UPFC technology
- **Resources to be expected**
  - Investors
  - Utility companies
  - Governmental agencies

Conclusions

- A cost-effective power flow control device has been developed.
- The new UPFC is modular, scalable, reliable, compact, lightweight, and highly efficient.
- The new UPFC can control voltage, compensate impedance, and shift phase angle, which has been verified experimentally.
- Large-scale test cases were used for study of:
  - Cost saving through congestion reduction;
  - Hourly dispatch for power flow control;
  - Reduction of loop flows;
  - Increase of wind power injection.