FREEDM Industry Advisory Board Minutes

May 3, 2018
10:00 am – 11:30 am US eastern

Attendees

Company	**Name**	**Membership Level**
ABB	Sandeep Bala	Full
Duke Energy	Kevin Chen	Full
Eaton	Miguel Chavez	Associate
EPRI	Bruce Rogers	Associate
FPL	Paul Taylor	Associate
SAS	Arnie de Castro	Associate
Schneider Electric	John Shea	Associate
Sensus	Jared Gregory	Associate
Total	Wente Zeng	Full
Weidmann	Giuseppe Gatti	Associate
FREEDM	Ken Dulaney Awal Alireza Dayerizadeh	

The meeting began with attendance and reading the antitrust statement.

We reviewed the agenda for the annual conference on June 6-8. The face to face IAB meeting will be June 6 at McKimmon and include presentations from faculty and a group discussion. June 7 is the public day and includes University speakers and keynotes from ARPA-E and the US Department of Defense. There are several industry panels planned for the conference. Ken clarified that we are not expecting presentations or slides but rather a focused discussion on the particular topic. The full agenda can be found in Appendix A.

IAB members are also encouraged to send Human Resource contacts to Ken so they can join the new email list focused on HR issues like career fairs, graduating students, etc. John Shea announced an IEEE Young Professionals meeting focused on hiring. He will send information to Ken.

FREEDM will also be represented at several upcoming conferences: IEEE Transportation Electrification Conference, IEEE Symposium on Power Electronics for Distributed Generation, and PAC World.

Ken provided an update on industry recruiting efforts. Risho is a materials company based in Japan, Kohler may provide a generator for in-kind membership, and Typhoon HIL expressed interest in membership after hosting a workshop for students at NC State.

There is an IAC meeting for the CREDENCE project with Irish Universities on May 17. FREEDM IAB members are welcome to join.

Ken shared a few interesting facts from his recent conferences:

- From the Microgrid Global Innovation Forum, he noted that audience members were very interested in FREEDM technologies but had questions on reliability in high temperature environments. Several member companies were also represented at the conference.
- A company here in Raleigh, Causam Energy, announced that they have an SEC compliant blockchain product.
- There was some discussion on the outage cost versus new generation question. The notion is that industrial customers will install expensive microgrids because they must have higher reliability. Arnie noted this has happened in pharmaceuticals and food products where downtime can cost millions per minute. Bruce noted that this is one business case for microgrids but is a relatively small segment of the microgrid market. He has not seen a large number of customers install microgrids. Paul said FPL customers have not expressed much interest either. Datacenters are one exception. They have asked to locate in strategic locations on the grid closer to transmission. Most companies want higher resiliency but are not willing to pay for it yet. He said Publix is a good example of backup generation use but not exactly microgrids.
- FREEDM was also well represented at the North Carolina State Energy Conference.

Next, Ali Dayerizadeh discussed his research in wireless power transfer for electric vehicle charging using emitting coils in the road and receiver coils in the vehicle. The FREEDM breakthrough involves reflexive field containment. The process does not require additional hardware or processing algorithms to activate emitter coils individually and instead relies on circuit design to achieve maximum coil coupling. Recent advances include a saturable inductor that reduces the magnetic fields in uncoupled condition and achieves current gains of 11x. Ali can be reached at adayeri@ncsu.edu. His presentation is in Appendix B.

M.A. Awal presented his work on distributed power electronic controls. He reviewed existing state of the art approaches for medium voltage DC using Modular Multilevel Converters and cascaded H-bridges that require very fast communications. To achieve true decentralized control requires applying non-linear control methods with distributed passive components. This can be achieved using high frequency switching. Applications include medium voltage AC to DC conversion and single stage power conversion for PV. Awal’s controller uses only local current and voltage measurements. This method allows for decentralized rather than just distributed control. One application for this methodology is for SST power module controls. The next stage of research is to move from simulation to prototype hardware controller. Awal’s email is mawal@ncsu.edu. His presentation is in Appendix C.

The call concluded at 11:10. The next meeting is face to face on June 6 at the Annual Conference.

Actions

1. Ken will reach out to individual members regarding panel participation.

Appendix A
Annual Conference Agenda

FREEDM SYSTEMS CENTER

Annual Conference Agenda
June 7- 8, 2018

Thursday, June 7		
McKimmon Center		
8:00am	Registration & Coffee	
8:30am	Introduction	Dr. Louis Martin-Vega, Dean of the College of Engineering, NCSU
8:35am	Welcome	Dr. Randy Woodson, Chancellor, NCSU
8:50am	Keynote Speaker	Dr. Sonja Glavaski, Program Director, ARPA e
9:30am	FREEDM Overview	Dr. Iqbal Husain, Director, FREEDM
9:50am	Graduate Education Programs	Dr. Mesut Baran, Professor and College Education Program Director, FREEDM
10:00am	Break	
10:20am	FREEDM Innovations	FREEDM Faculty
11:40am	National Science Foundation Presentation	Dr. Carmiña Londoño, National Science Foundation
11:50am	Industry Speaker	Dr. Iulian Nistor, Department Manager, Corporate Research, ABB
12:00pm	Lunch and Networking	
1:00pm	Introduction to Perfect Pitch	Susan Sanford, Research Triangle Cleantech Cluster
1:10pm	Perfect Pitch Contest	FREEDM Students
1:30pm	Grid Resiliency	Faculty and Industry Panel
2:15pm	Education and Workforce	Dr. Pam Carpenter, Director of Education and Workforce Development, FREEDM
2:25pm	Alumni Speaker	Likhita Ravuri, Research Electrical Engineer, Voltserver
2:35pm	FREEDM and Power America	Dr. Dan Stancil, Department Head, Electrical and Computer Engineering, NCSU
2:50pm	Break	
3:05pm	Energy Priorities for Department of Defense Installations	Joseph Corrigan, Senior Advisor, Kelley Drye
3:45pm	Research Project Summaries	FREEDM PhD Candidates
4:30pm	Poster Session	
5:30pm	Transition to Alumni Center	

FREEDM 10 Year Celebration		
The Dorothy and Roy Park Alumni Center		
6:00pm – 8:00pm	Reception & Dinner with Special Guest Speaker	Nelson Peeler, Duke Energy

FREEDM
SYSTEMS CENTER

Annual Conference Agenda
June 7- 8, 2018

Friday, June 8

McKimmon Center

8:00am	Registration and Coffee	
8:30am	Introduction	Dr. Iqbal Husain, Director, FREEDM
8:40am	Alumni Speaker	Kat Sico, Substation Engineer, Duke Energy
8:50am	Power of Data Analytics	Faculty and Industry Panel
9:30am	Alumni Speaker	Arvind Govindaraj, Hardware Engineer, Verily (Google) Life Sciences
9:40am	Power Electronics on the Grid	Faculty and Industry Panel
10:20am	Break	
10:40am	Advances in EV Deployment	Faculty and Industry Panel
11:20am	NC Storage Project Update	Dr. Joe DeCarolis, Associate Professor, NCSU Civil Engineering
11:40am	Faculty Research Highlights	Lunch with your favorite researcher
12:00pm	Lunch and Transition to Lab	

Keystone Science Center

1:00pm – 2:30pm	Review of Simulation Lab, High Bay and Low Bay	Keystone Science Center

Appendix B
Saturable Inductors for Wireless Power Transfer

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Saturable Inductors for Superior Reflexive Field Containment in Inductive Power Transfer Systems

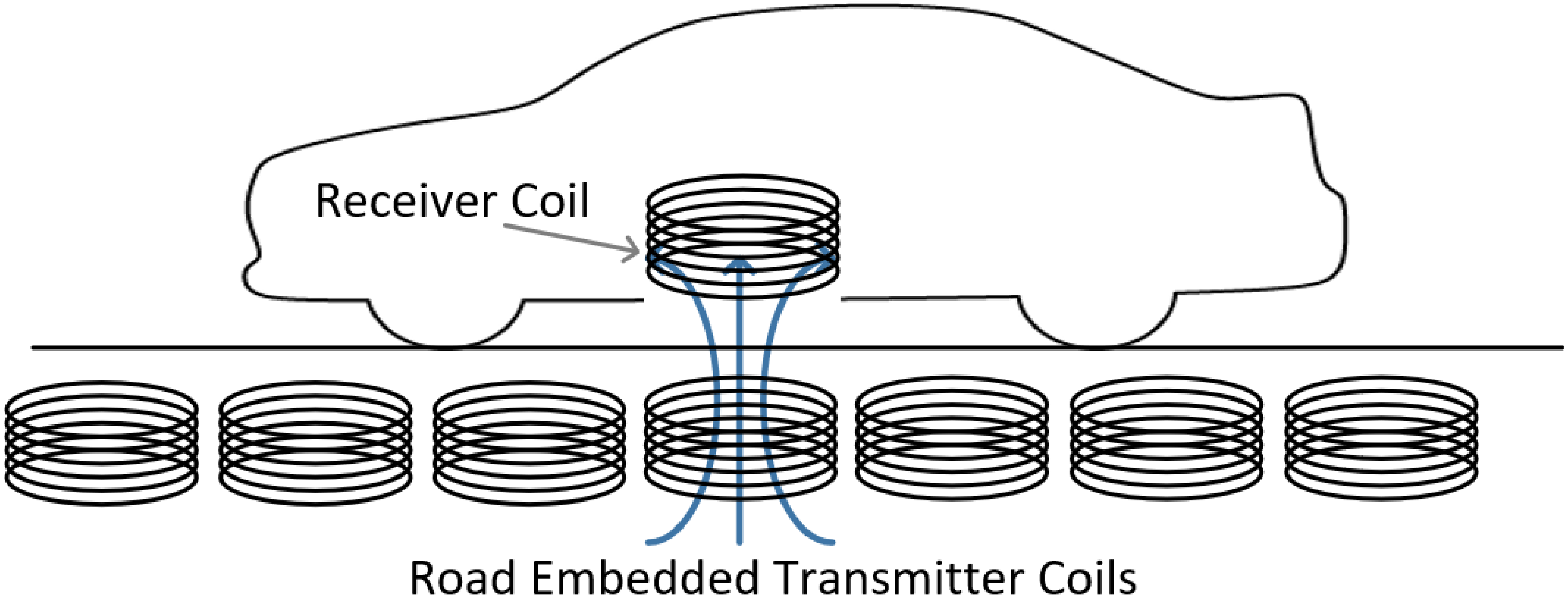
NCSU Invention Disclosure: 18-084

Alireza Dayerizadeh
Dr. Srdjan Lukić

Dynamic Wireless Power Transfer

Wireless Power Transfer: An Alternative to Conductive Charging.

- Source to load efficiencies of over 90% are possible at coupling coefficients of .2.



Roadway Embedded Dynamic Wireless Power Transfer Systems Allow for:

- Increased range and reduced charging times.
- Reduced vehicle energy storage requirements

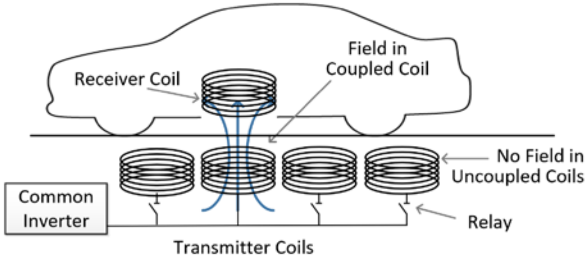
Reflexive Field Containment

Dynamic WPT may be accomplished through an array of segmented transmitting coils that sequentially couple to a passing receiving coil, thus isolating the field emissions to the coupled coil. Challenges include:

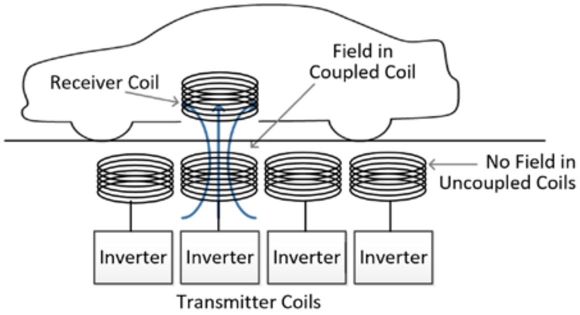
- Precise Receiver Position Feedback is required.
- Efficient and fast methodology to selectively energize coupled coil.

Possible Approaches

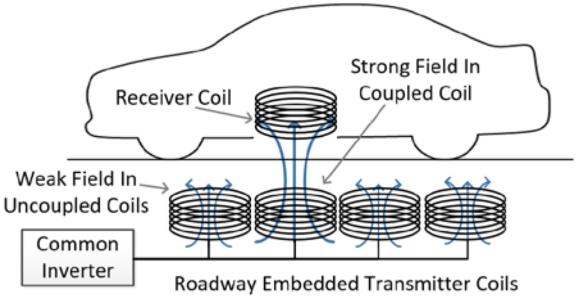
We will focus on this approach.



Position sensor and relays for power flow control to coupled coils.

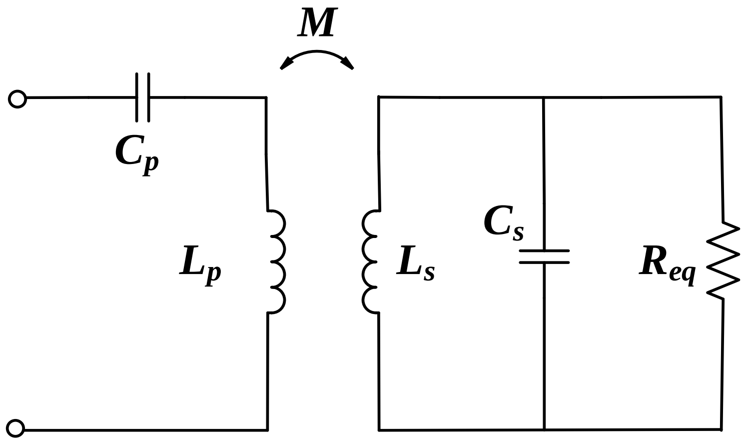


Power each coil with a dedicated inverter (cost prohibitive in large applications).

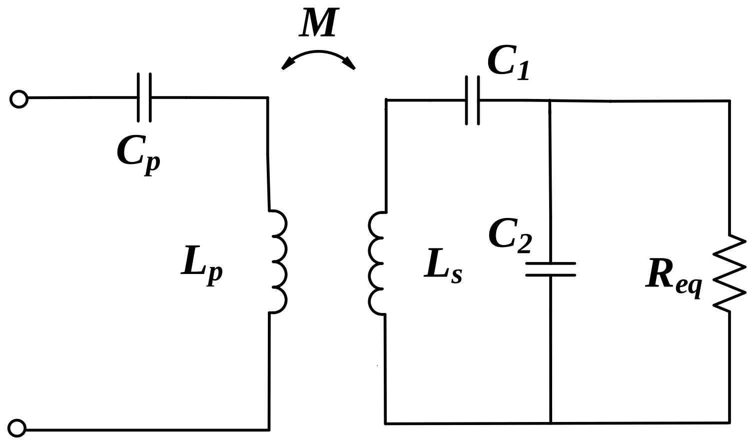


Exploit reflected impedance of receiving coil to control emitted field reflexively

Reflexive Field Containment Approach



Series-Parallel

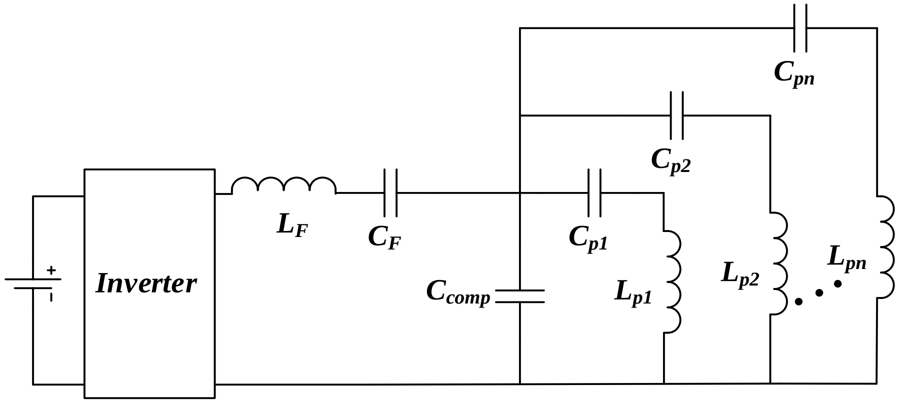


Series-Parallel-LCC

$$Z_{reflected} = \frac{(\omega M)^2}{Z_s} = \frac{M^2 R_{eq}}{L_s^2} - \boxed{j\frac{\omega M^2}{L_s}}$$

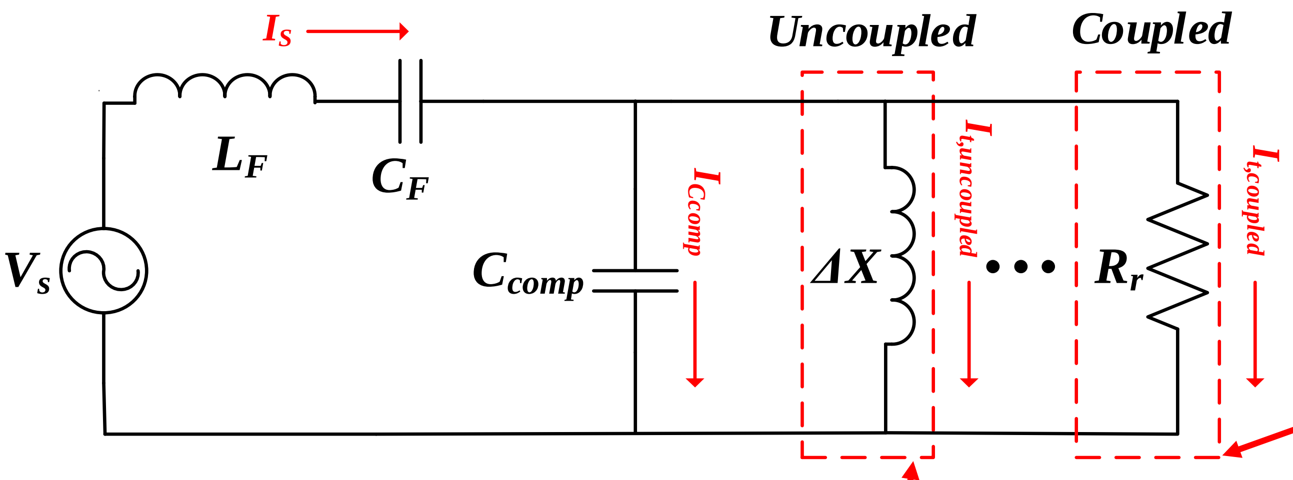
$$Z_{reflected} = \frac{(\omega M)^2}{Z_s} = \frac{M^2 R_{eq}}{L_s^2} \cdot n^2 - n \cdot j\frac{\omega M^2}{L_s} = \frac{\omega M^2}{L_s}(Q_{Total} \boxed{- n \cdot j)}$$

- Large uncompensated Inductive reactance limits current flow in uncoupled TX coils.
- TX compensation is such that it's resonance is offset from the system operating frequency.
- Reflected capacitive reactance is exploited to bring the TX coil into resonance and boost current flow.



Allows for Segmented TX Coils

Transmitter Design



$$I_{Ccomp} = V_s \cdot j\omega C_{comp}$$

$$I_s = V_s \cdot \left(j\omega C_{comp} \frac{N_{coupled}}{N_{Total}} + \frac{N_{coupled}}{R_r} \right)$$

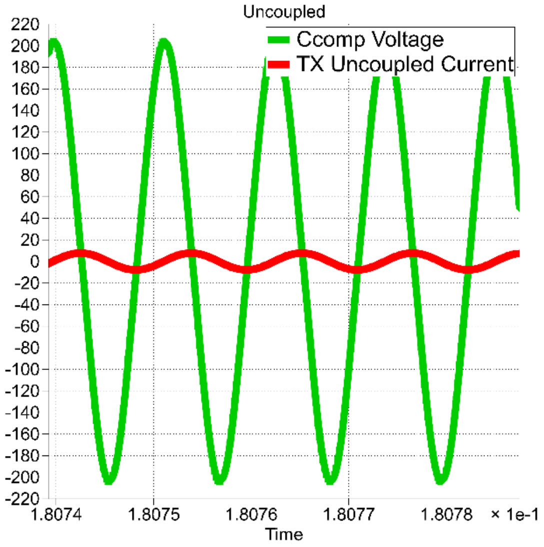
$$I_{t,coupled} = \frac{V_s}{R_r}$$

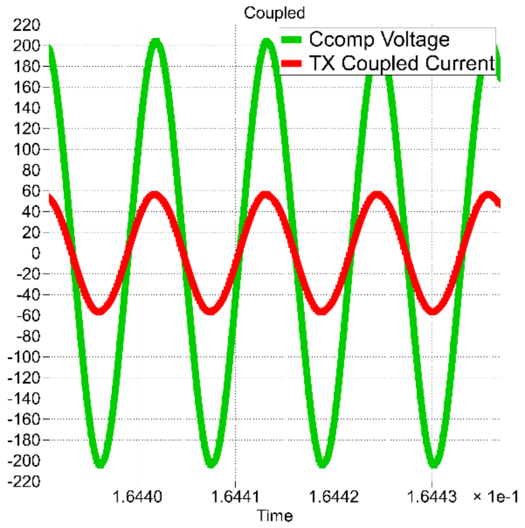
Inverter sees real load in coupled sections and Current is boosted.

$$I_{t,uncoupled} = \frac{V_s}{j\Delta X}$$

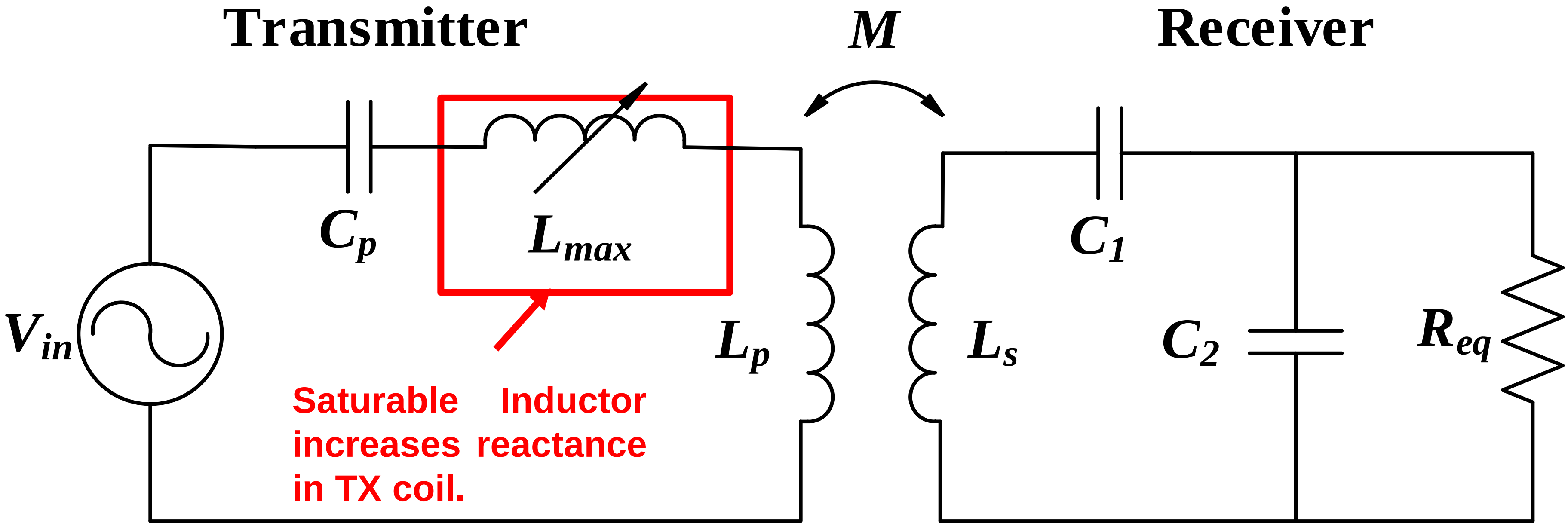
$$Z_p = j\omega L_p + \frac{1}{j\omega C_{p1}} = j\Delta X$$

Due to the large reactance, current in uncoupled coils is attenuated, resulted in reduced magnetic field emissions.





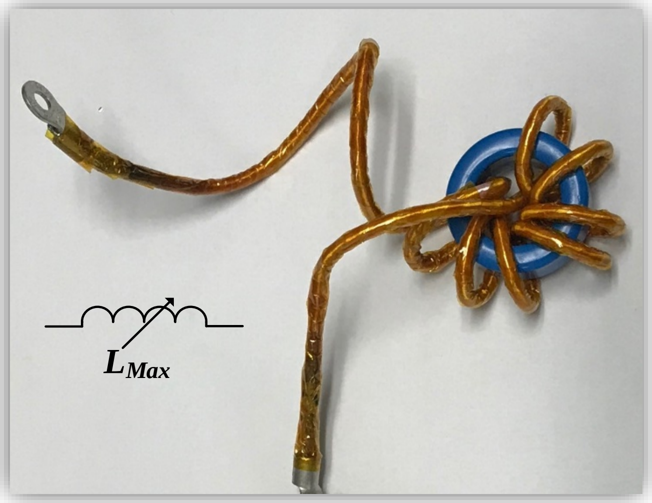
Improving Field Containment



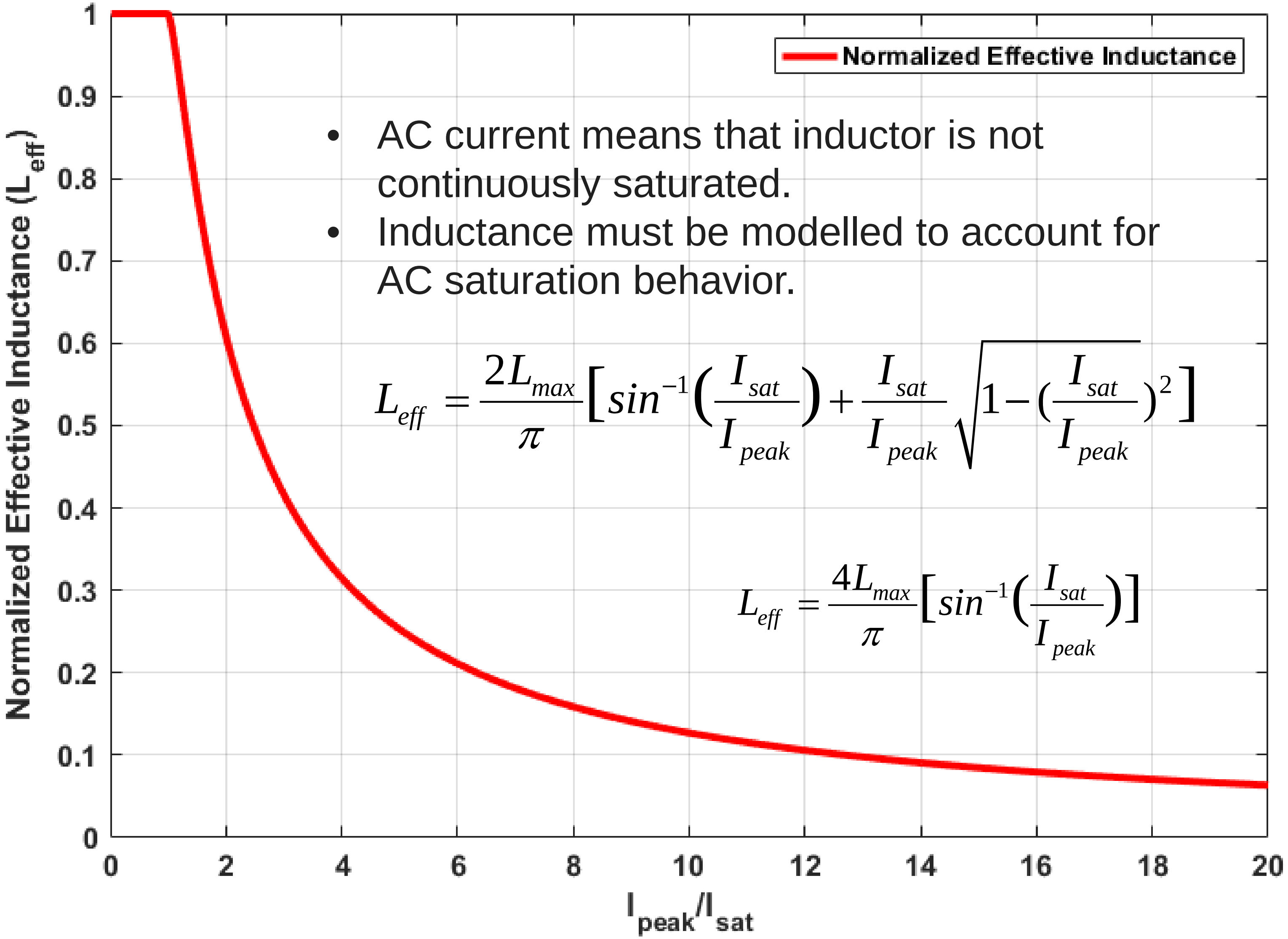
Saturable Inductor increases reactance in TX coil.

The Saturable inductor:

- Maximizes the difference between coupled and uncoupled currents in the TX coil.
- Saturates as the system becomes coupled.
- Improves system current gain (and field attenuation performance).



Saturable Inductor Characteristics



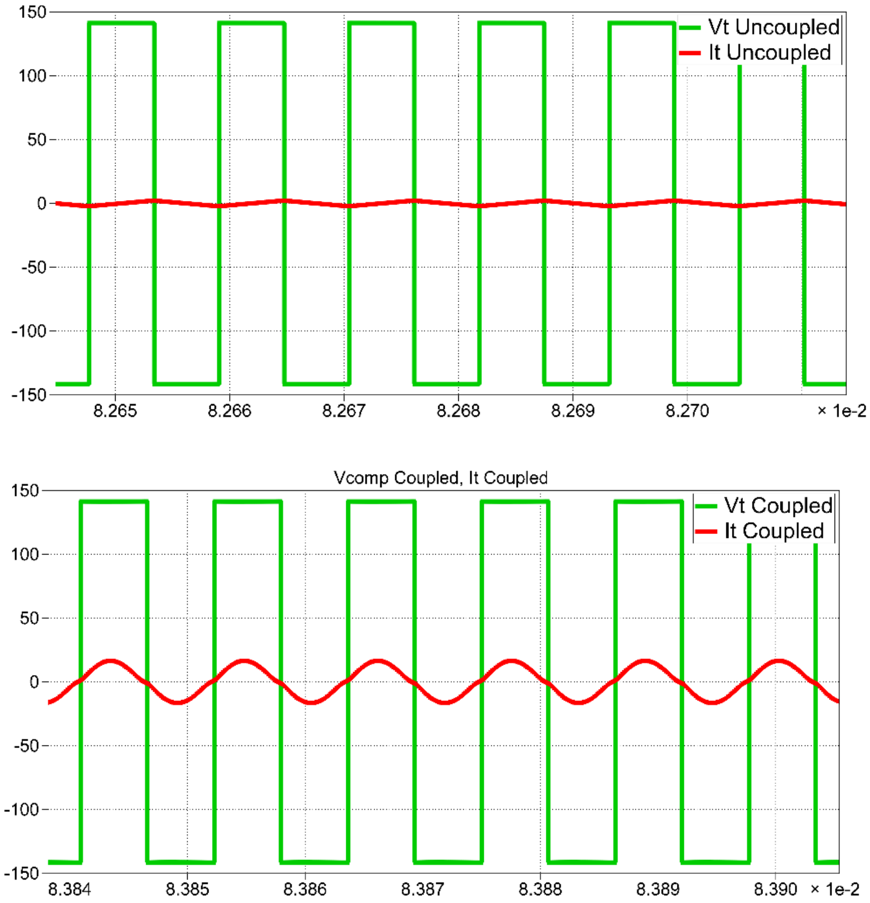
- AC current means that inductor is not continuously saturated.
- Inductance must be modelled to account for AC saturation behavior.

$$L_{eff} = \frac{2L_{max}}{\pi}\left[\sin^{-1}\left(\frac{I_{sat}}{I_{peak}}\right) + \frac{I_{sat}}{I_{peak}}\sqrt{1-\left(\frac{I_{sat}}{I_{peak}}\right)^{2}}\right]$$

$$L_{eff} = \frac{4L_{max}}{\pi}\left[\sin^{-1}\left(\frac{I_{sat}}{I_{peak}}\right)\right]$$

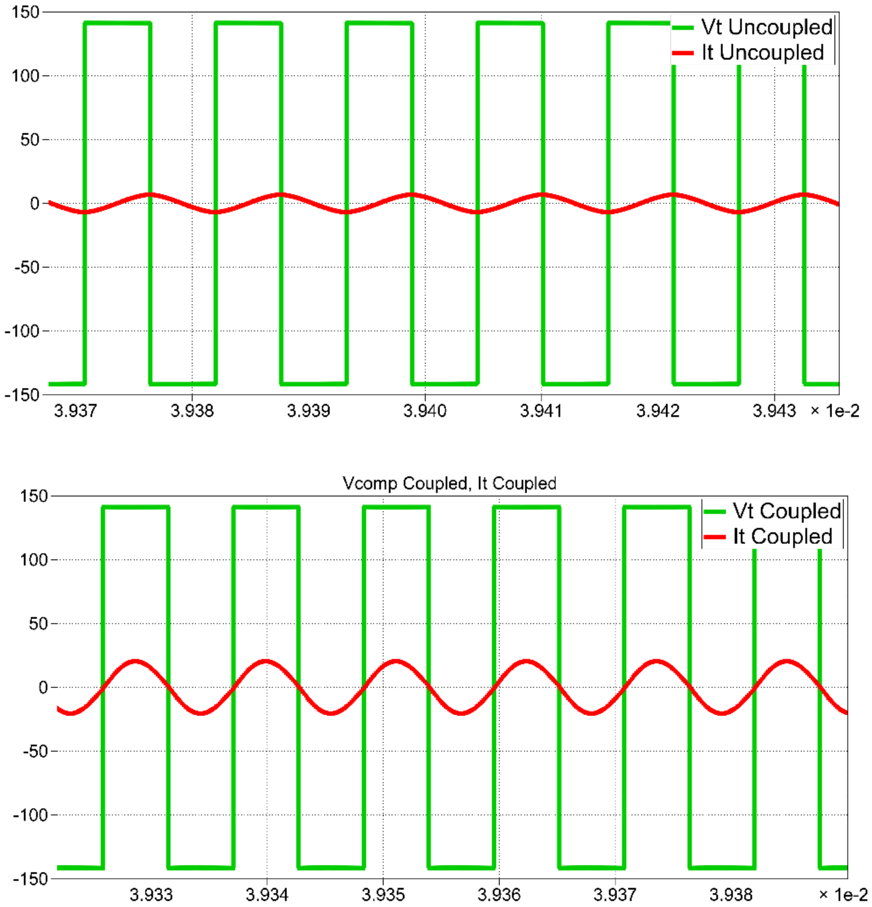
Simulation – Comparison to Reference System

System With Saturable Inductor



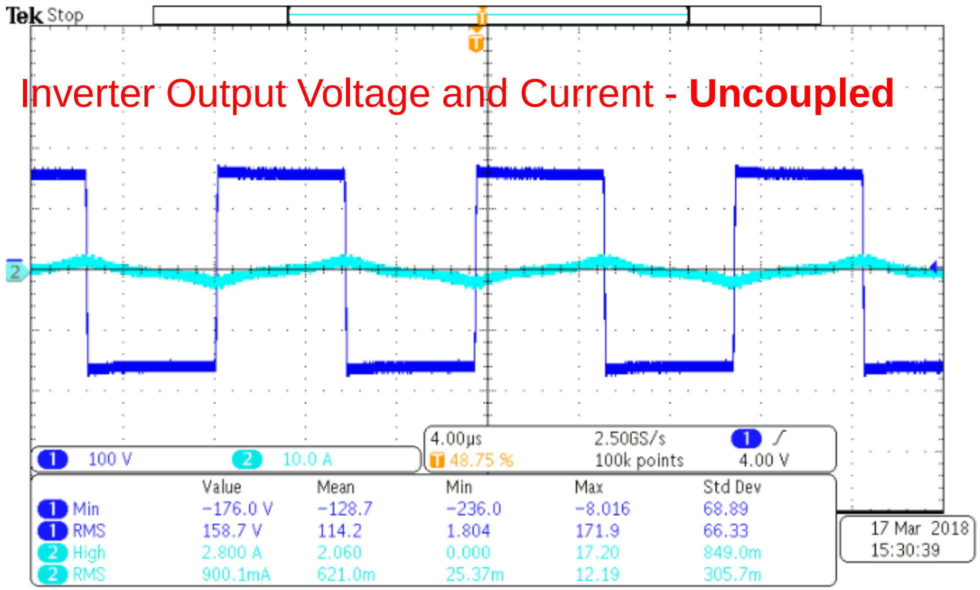
Current gain ~ 11

Reference System



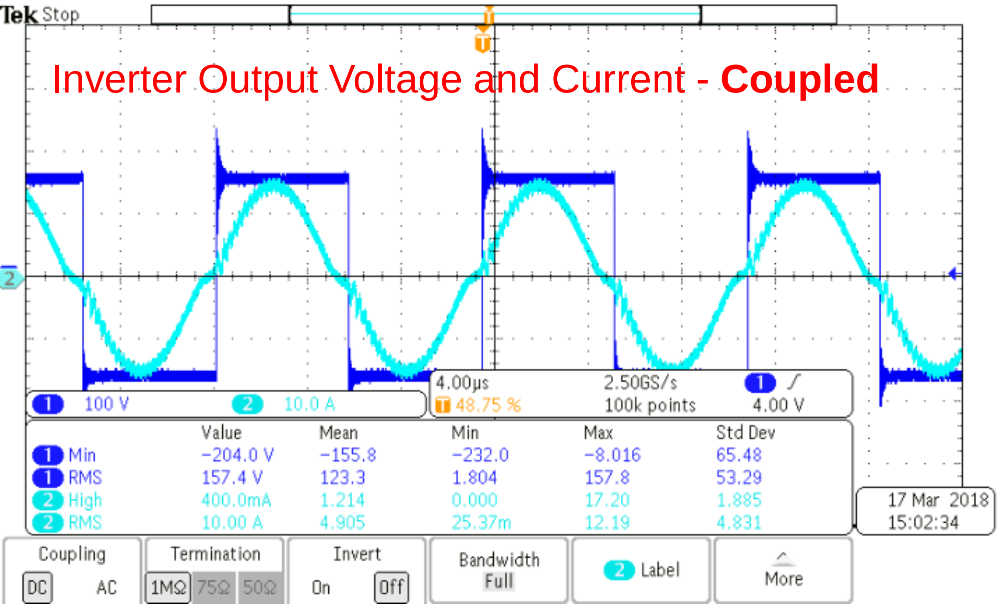
Current gain ~ 3

Hardware Validation



Inverter Output Voltage and Current - **Uncoupled**

	Value	Mean	Min	Max	Std Dev
1 Min	−176.0 V	−128.7	−236.0	−8.016	68.89
1 RMS	158.7 V	114.2	1.804	171.9	66.33
2 High	2.800 A	2.060	0.000	17.20	849.0m
2 RMS	900.1mA	621.0m	25.37m	12.19	305.7m

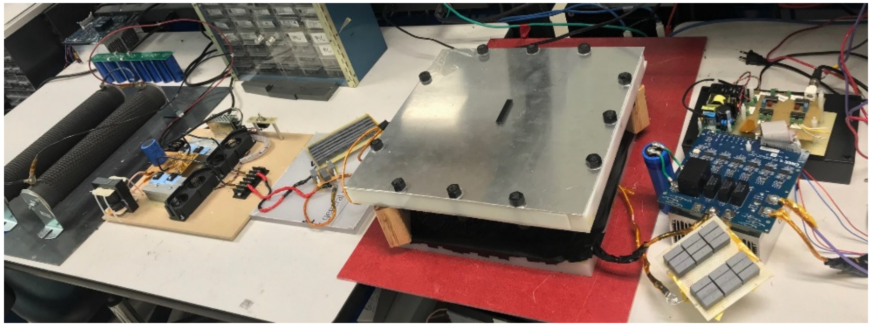


Inverter Output Voltage and Current - **Coupled**

	Value	Mean	Min	Max	Std Dev
1 Min	−204.0 V	−155.8	−232.0	−8.016	65.48
1 RMS	157.4 V	123.3	1.804	157.8	53.29
2 High	400.0mA	1.214	0.000	17.20	1.885
2 RMS	10.00 A	4.905	25.37m	12.19	4.831

Transmitter (TX)*	
L_p	190uH
C_p	22.65nF
L_{max}	180uH
L_{eff}	23uH
C_{sat}	143nF

Receiver System	
L_s	237uH
C_1	16.56nF
C_2	82.81nF
n	6
R_{Load}	7.5



Input Voltage	171.1 V
Input Current	8.65 A
Input Power	1480 W
Output Power	1208.4 W (95.2^2/7.5)
Efficiency	81.6%
Current Gain	**11.1**

Appendix C
Modular Redundant Medium Voltage Power Electronic Control

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Modular Redundant Medium Voltage Power Electronics Enabled By Decentralized Control

M A Awal

Advisers: Iqbal Husain, Wensong Yu

3 May, 2018

State-of-the-Art for Medium/High Voltage Application

Modular Multilevel Converter(MMC)

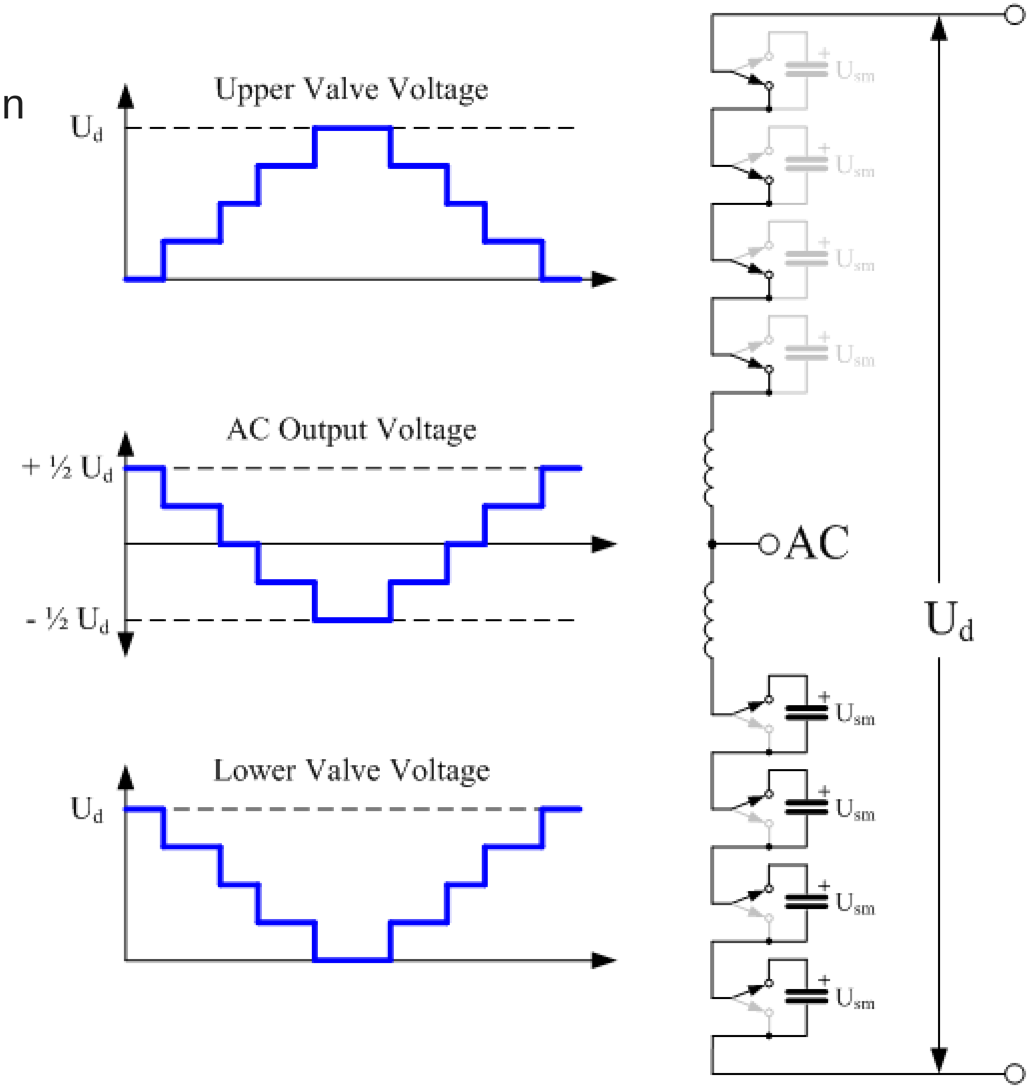
- Widely popular for HVDC application
- Solid State Transformers
- MV fast chargers

Pros

- Modular design
- Low switching frequency

Limitations

- Centralized controller
- Heavily communication(between modules and submodules) dependent



True modularity has not been achieved in terms of control

State-of-the-Art for Medium/High Voltage Application

Cascaded H-Bridge (CHB)

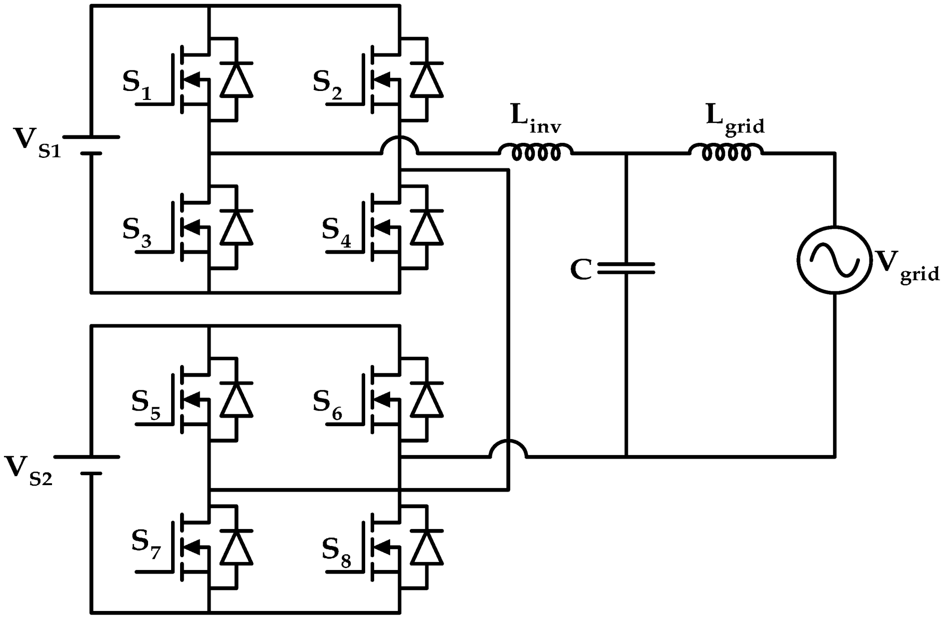
- Popular for SST application
- Industrial motor drives

Pros

- Modular design
- Low switching frequency

Limitations

- Centralized controller
- Heavily communication(between modules and submodules) dependent
- Distributed/pseudo decentralized control has been proposed requiring some form of communication

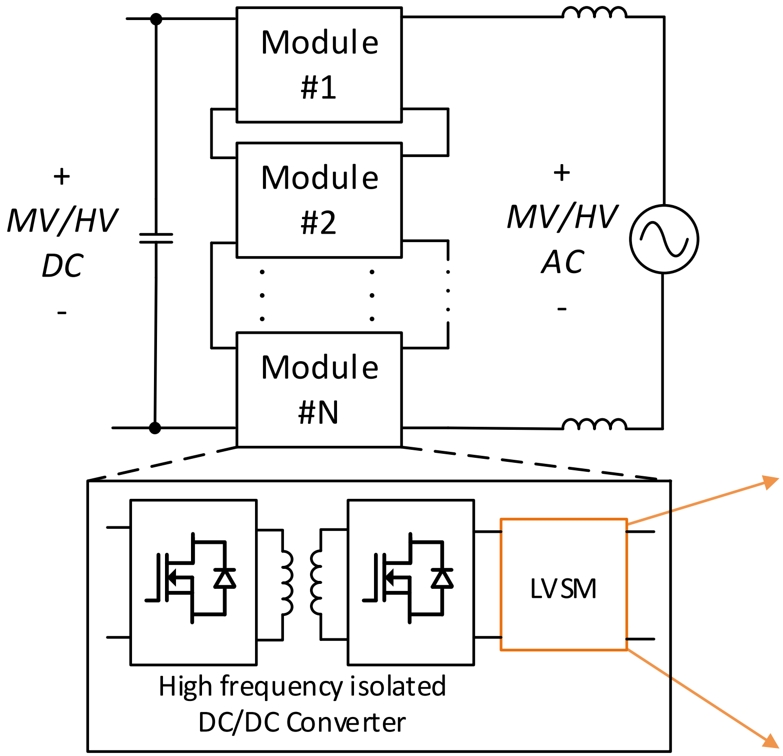


True modularity has not been achieved in terms of control

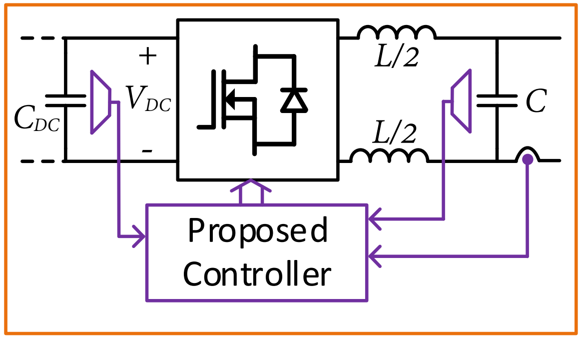
Achieving True Modularity

Key Innovations

- Apply non-linear control to achieve complete decentralized control of each module without any communication
- Switch at highest possible frequency leveraging widebandgap power devices
- Distribute passive filter components among modules

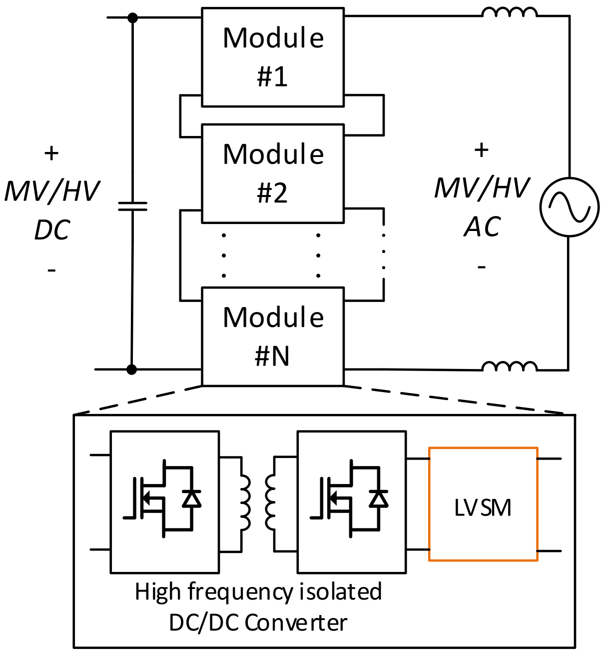


- Two different type of controllers have been proposed
- **Phase coupled linear controller**
- **Second order time domain controller**

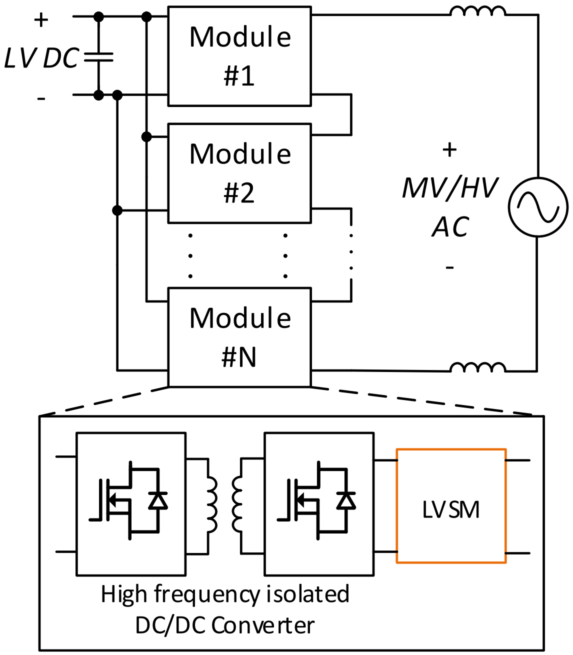


Low Voltage Sub Module

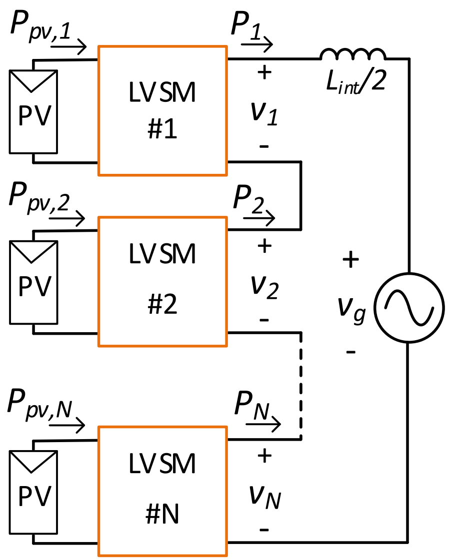
Possible Applications



Input-Series-Output-Series MV\HVAC to MV\HVDC

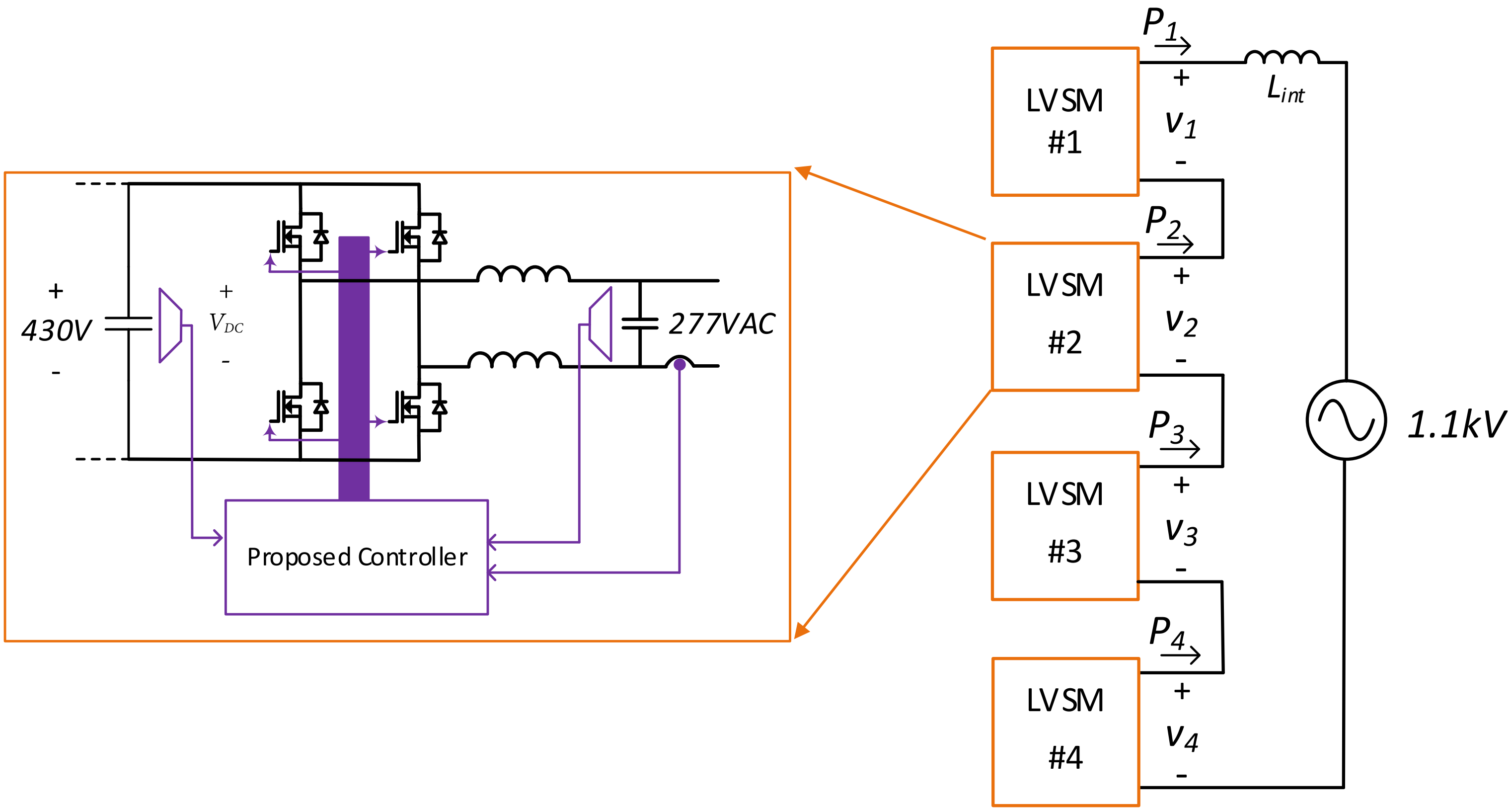


Input-Series-Output-Parallel MV\HVAC to MV\HVDC



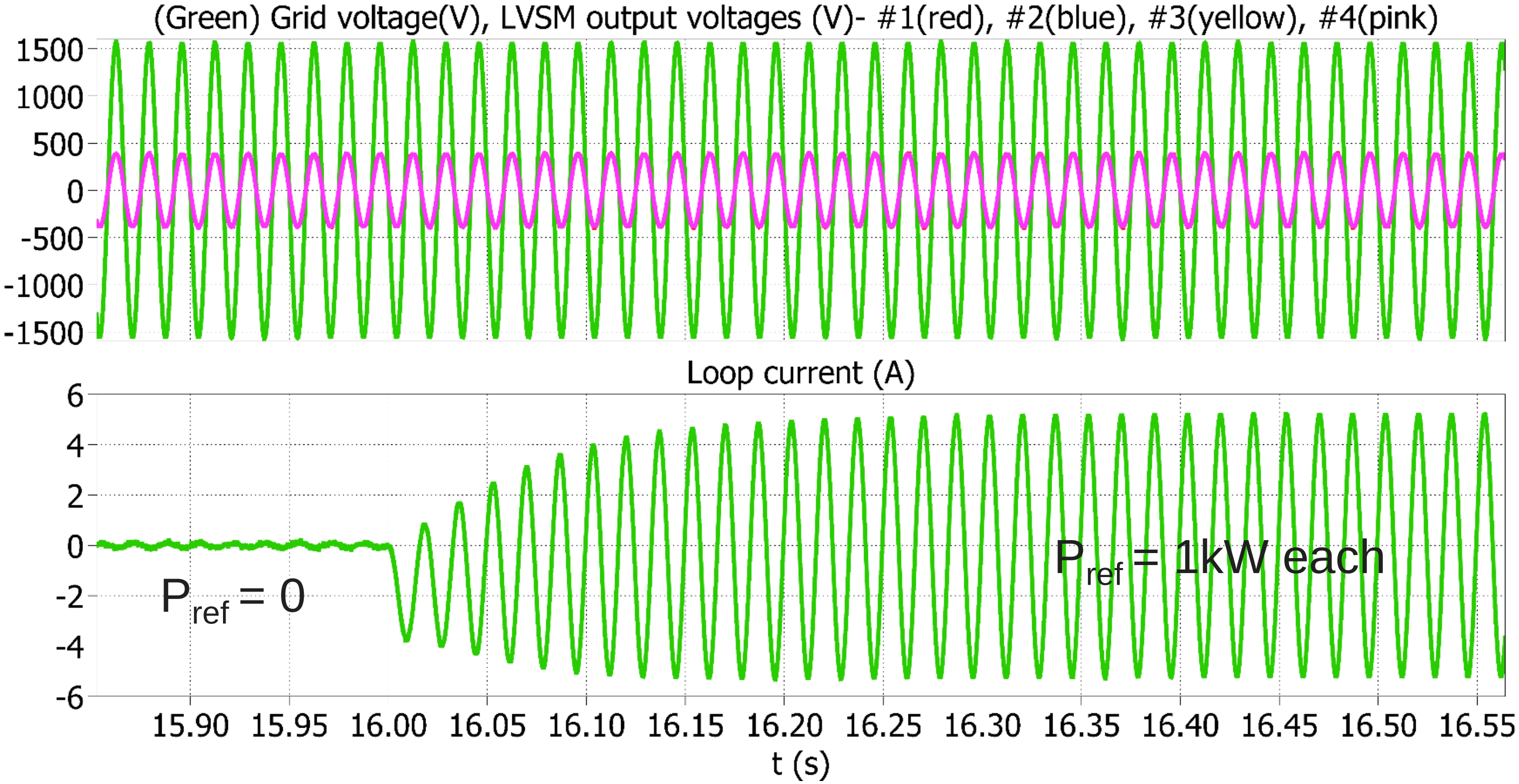
Single stage power conversion for PV Application

Reaching Medium Voltage AC



- Simulation done for single phase system
- Four LVSMs used, each with a 430V DC bus and 277VAC output
- 4 X 277 = 1.1kVAC used to emulate grid
- Possible for three phase systems

Reaching Medium Voltage AC



- Simulation done for single phase system
- Four LVSMs used, each with a 430V DC bus and 277VAC output
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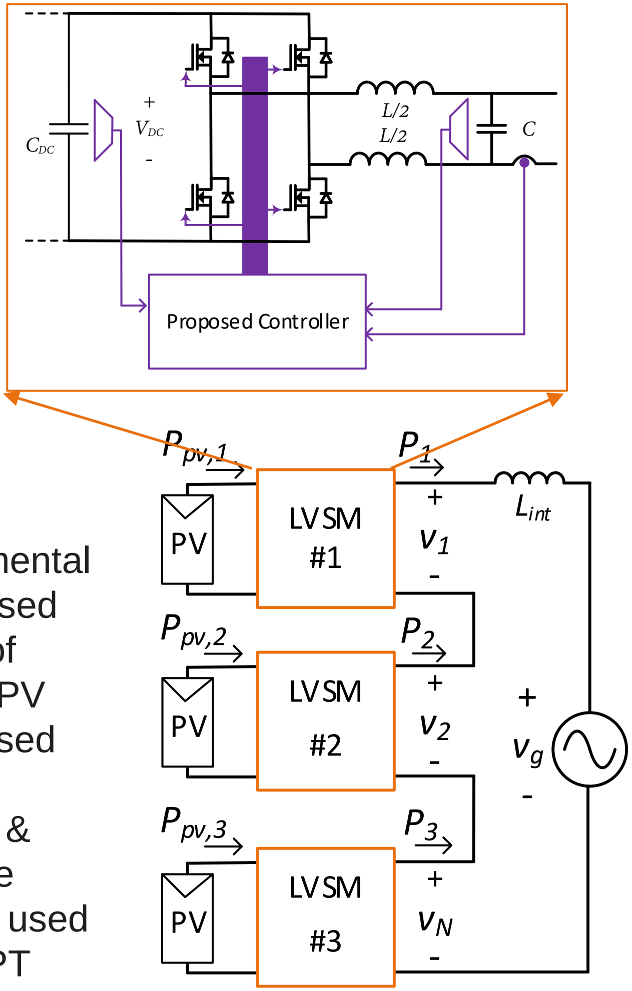
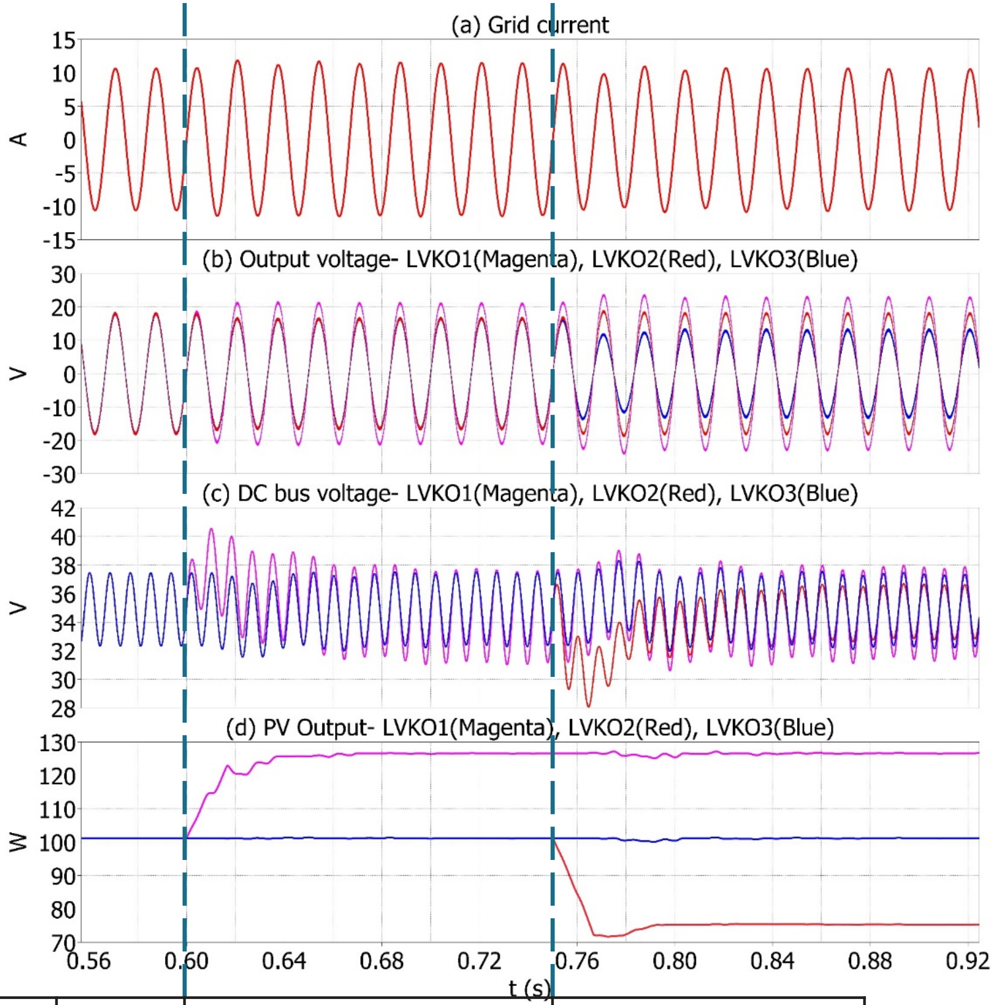
Panel Level MPPT in AC Stacked PV Inverter



- Experimental data based model of BP365 PV panel used
- Perturb & Observe method used for MPPT



Solar irradiance:

PV panel #1	80%	100%	100%
PV panel #2	80%	80%	60%
PV panel #3	80%	80%	80%

Current State of Research & Future Work

- Switching model simulation completed
- HIL test in progress
- Hardware test with scaled down rating in progress
- Paper accepted for ECCE 2018

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