

# FACTS Control for Long- and Short-Term Energy Storage

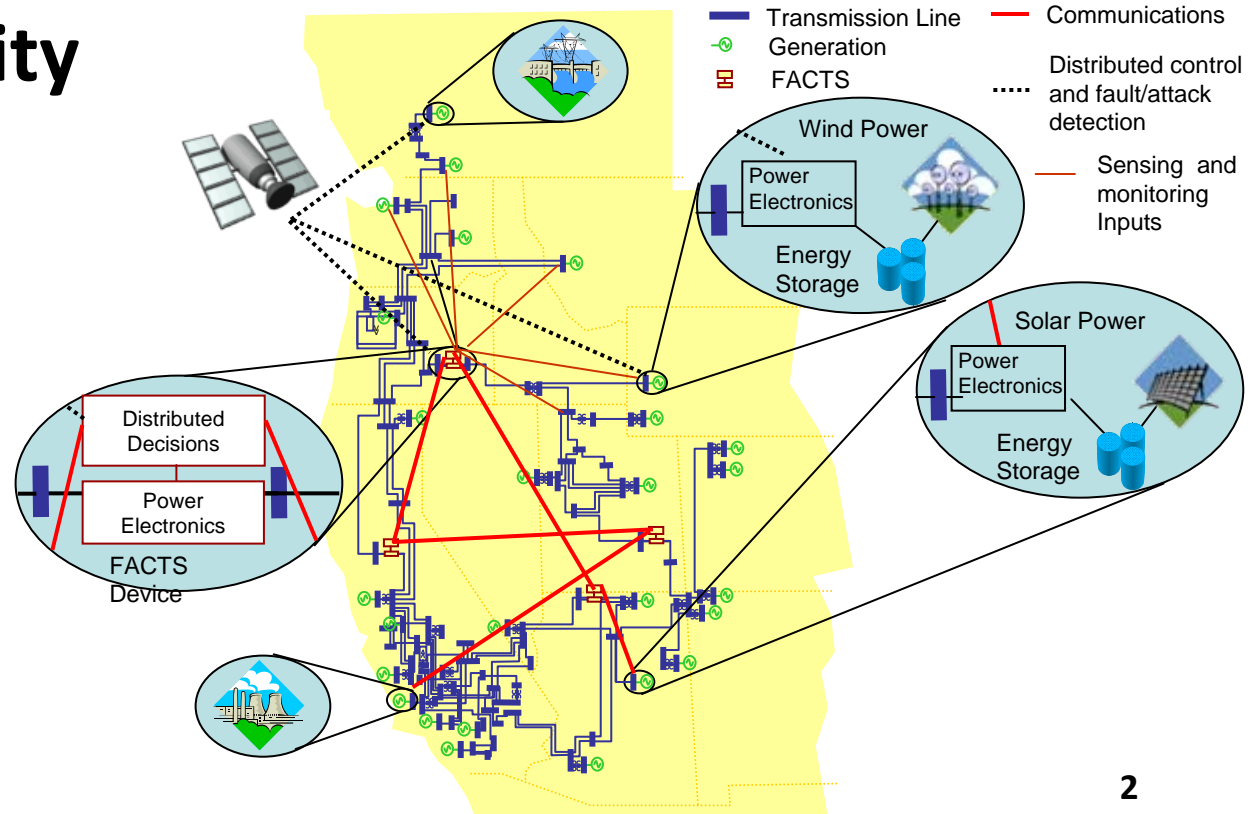
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# Issues

- Short- and Long-Term Energy Storage
- Storage Integration
- Cyber Security

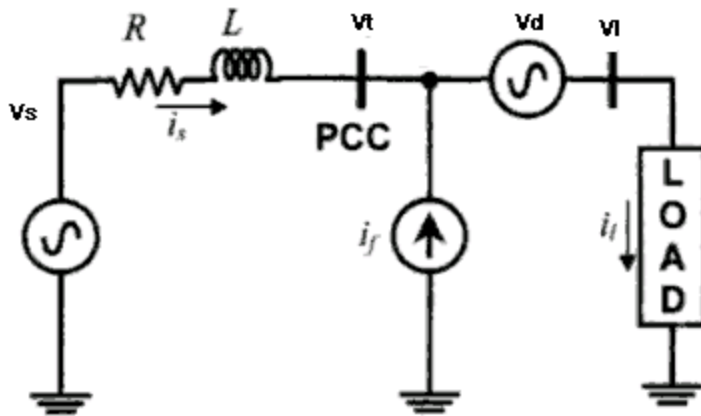


## Part I

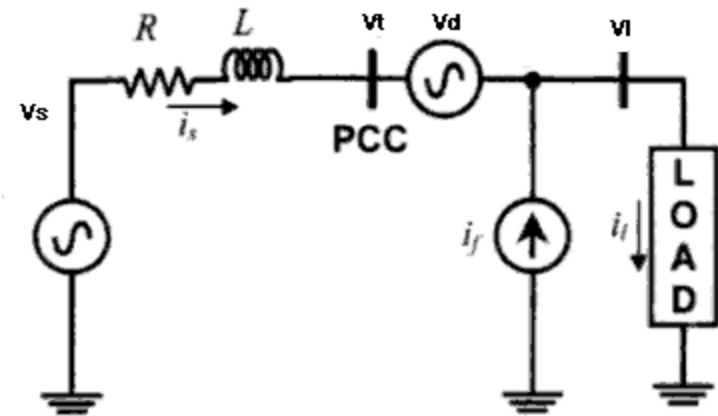
# UPQC Integrated with an EC & DC-DC Converter

# Unified Power Quality Controller

- Provides bi-directional protection for load and system

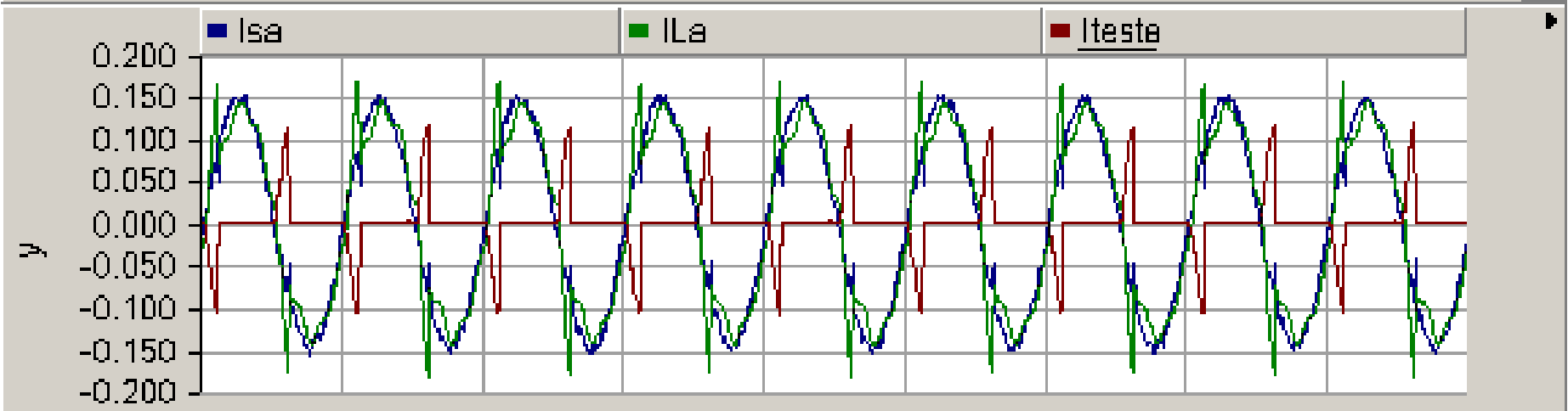
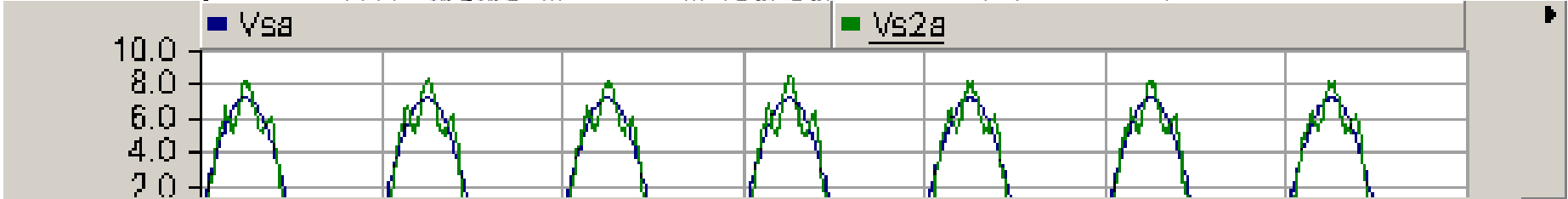
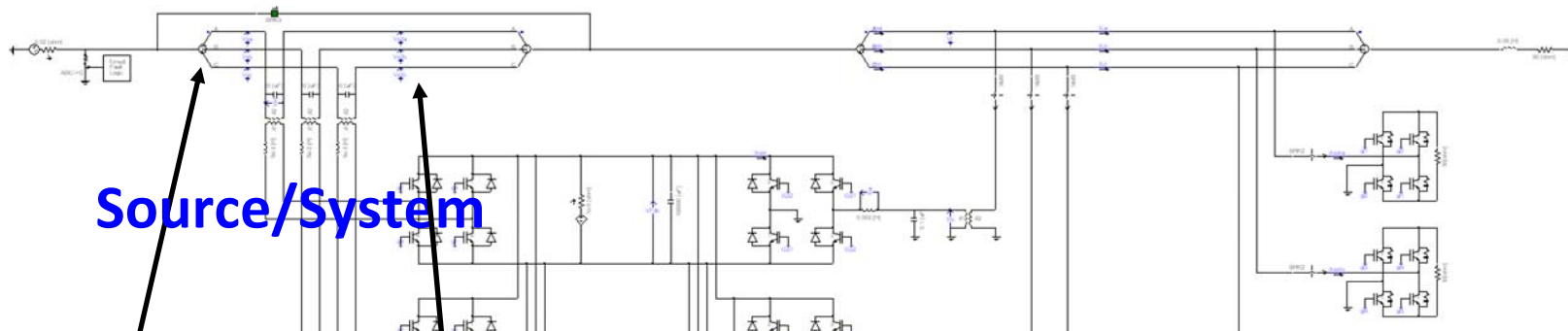


Left-Shunt (LS) UPQC

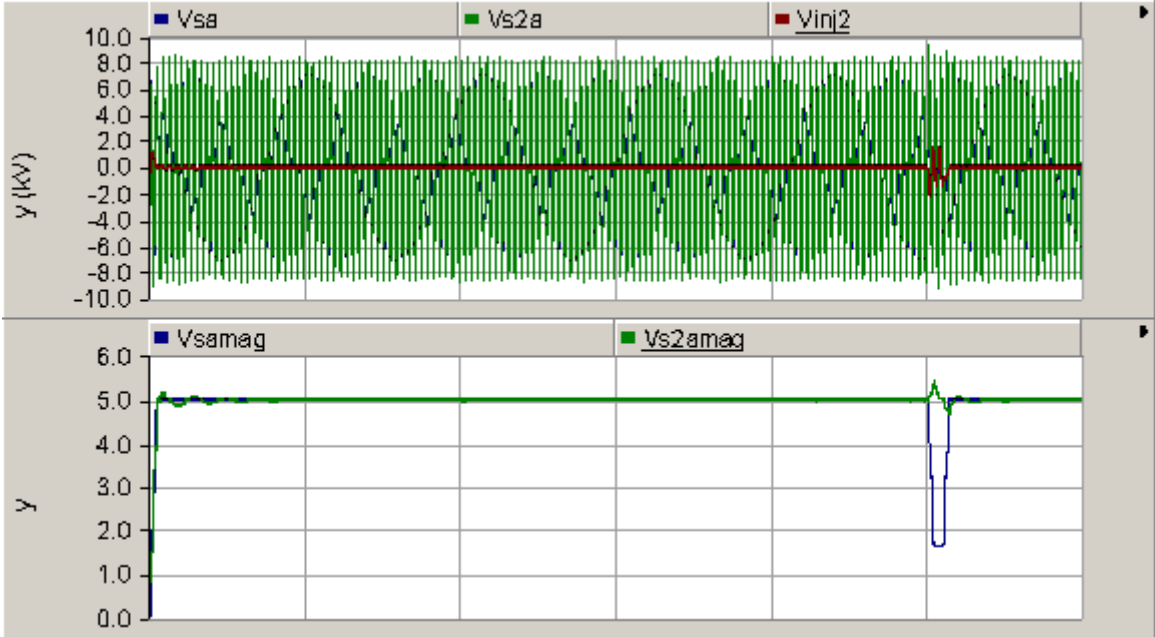


Right-Shunt (RS) UPQC

# PSCAD Results



# Short-Circuit Fault



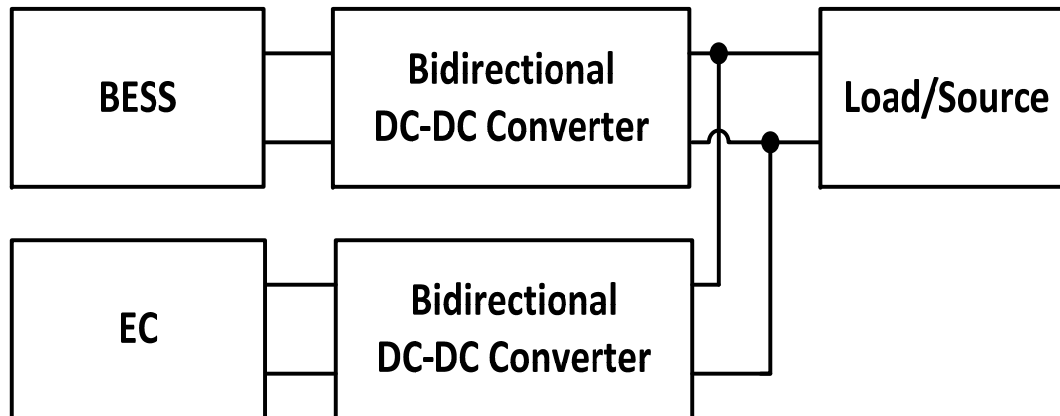


## Part II

# Hybrid Energy Storage Systems: BESS + ECs

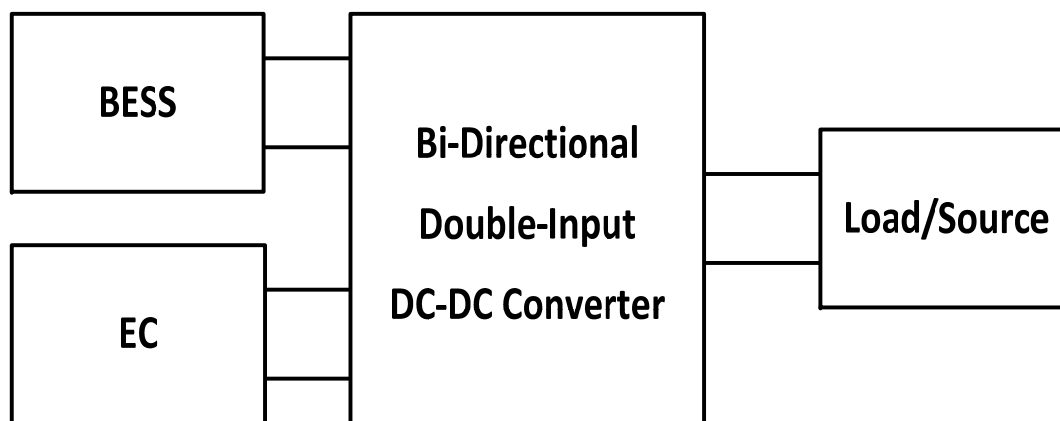


# Hybrid Energy Storage System with Multiple Converters

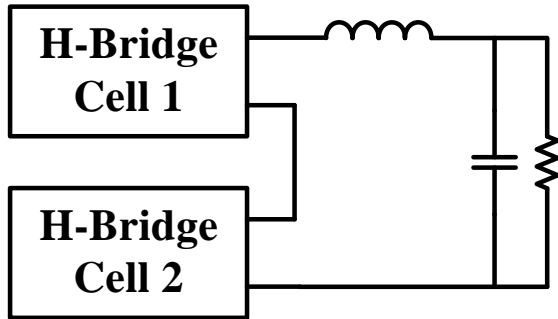


# Double-Input Converters (DIC)

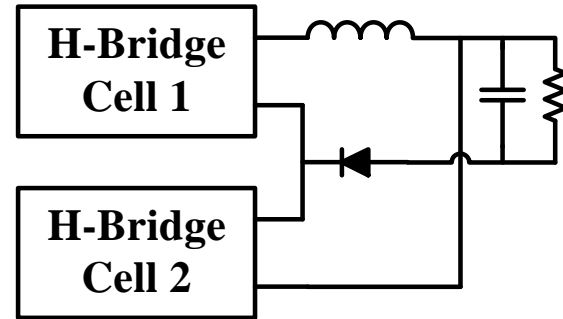
- They integrate different power sources while each one is allowed to have a different power rating
- Decreased Cost; Increased Reliability



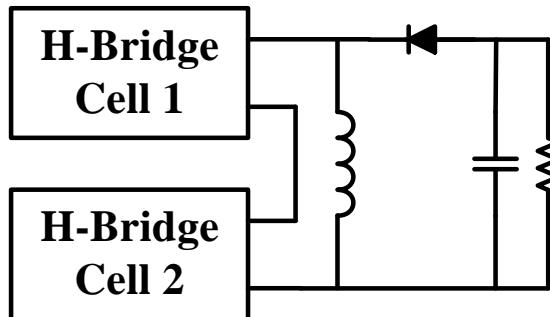
# Derivation of DICs Using H-Bridge Cell



Double-Input Buck-Buck

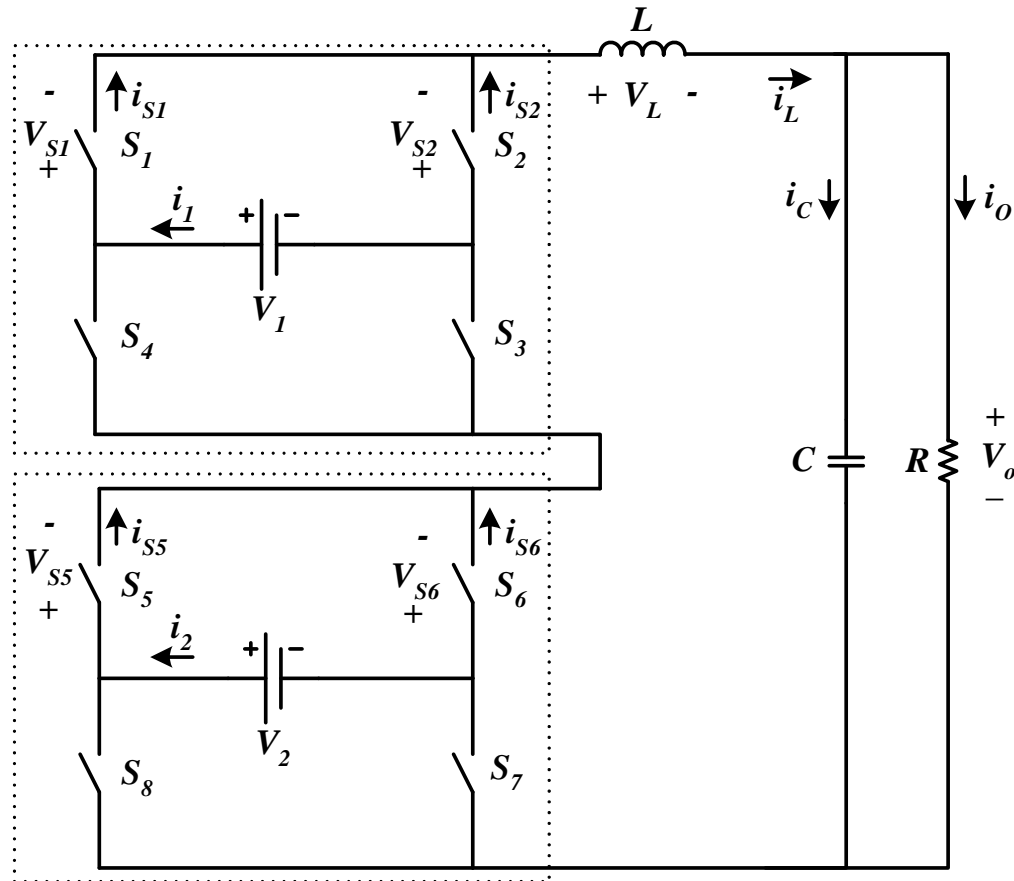


Double-Input Buck-Buckboost

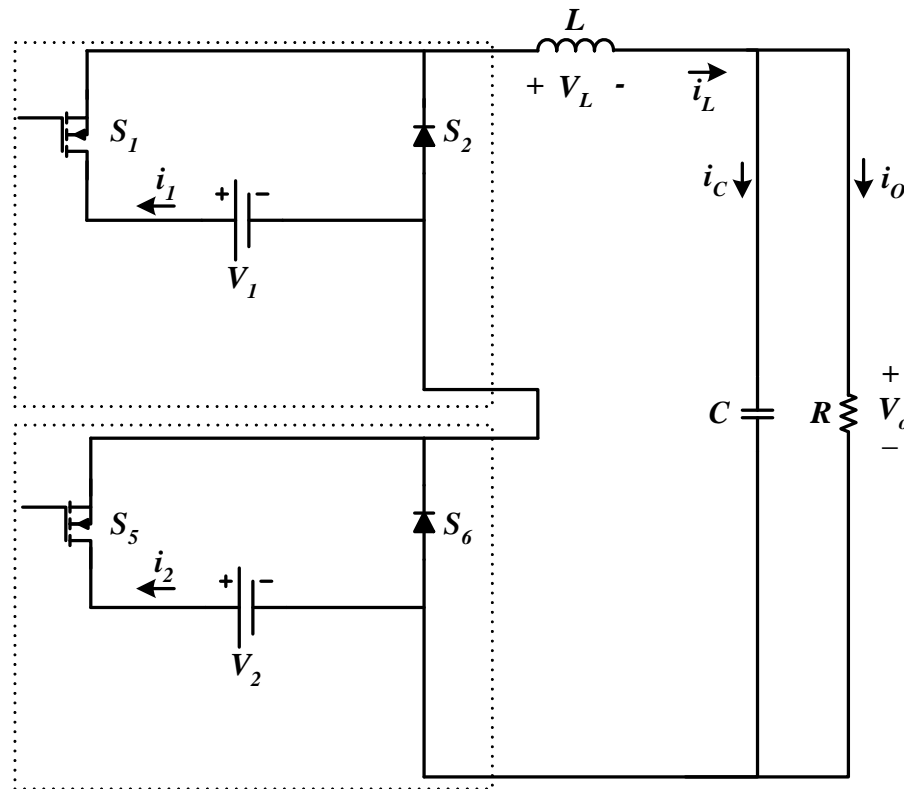


Double-Input Buckboost-Buckboost

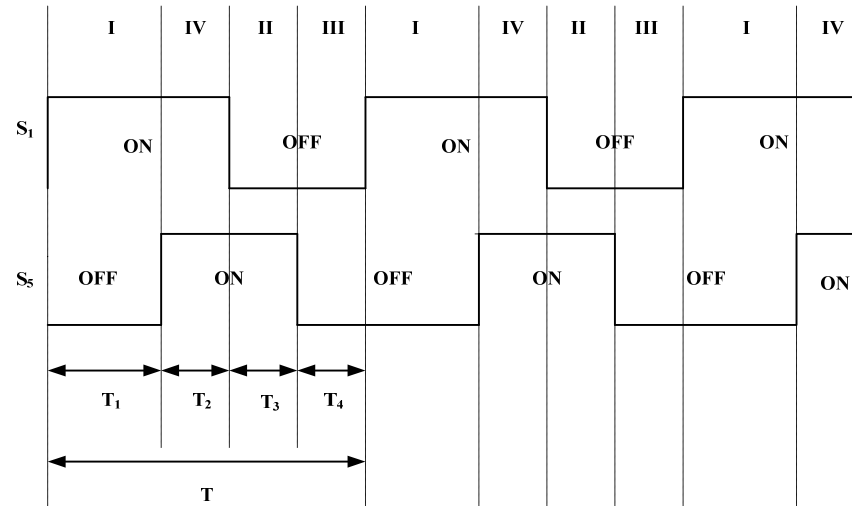
# Double-Input Buck-Buck Converter



# Simplified Double-Input Buck-Buck Converter



# Voltage Transfer Ratios



## Buck-Buck

$$V_o = d_1 * V_1 + d_2 * V_2$$

## Buck-Buckboost

$$V_o = \frac{d_1}{1-d_2} * V_1 + \frac{d_2}{1-d_2} * V_2$$

## Buckboost-Buckboost

$$V_o = \frac{d_1}{1-d_1-d_2 + \frac{T_2}{T}} * V_1 + \frac{d_2}{1-d_1-d_2 + \frac{T_2}{T}} * V_2$$

## Part III

# Detecting and Preventing Interference in Cooperating Power Electronics

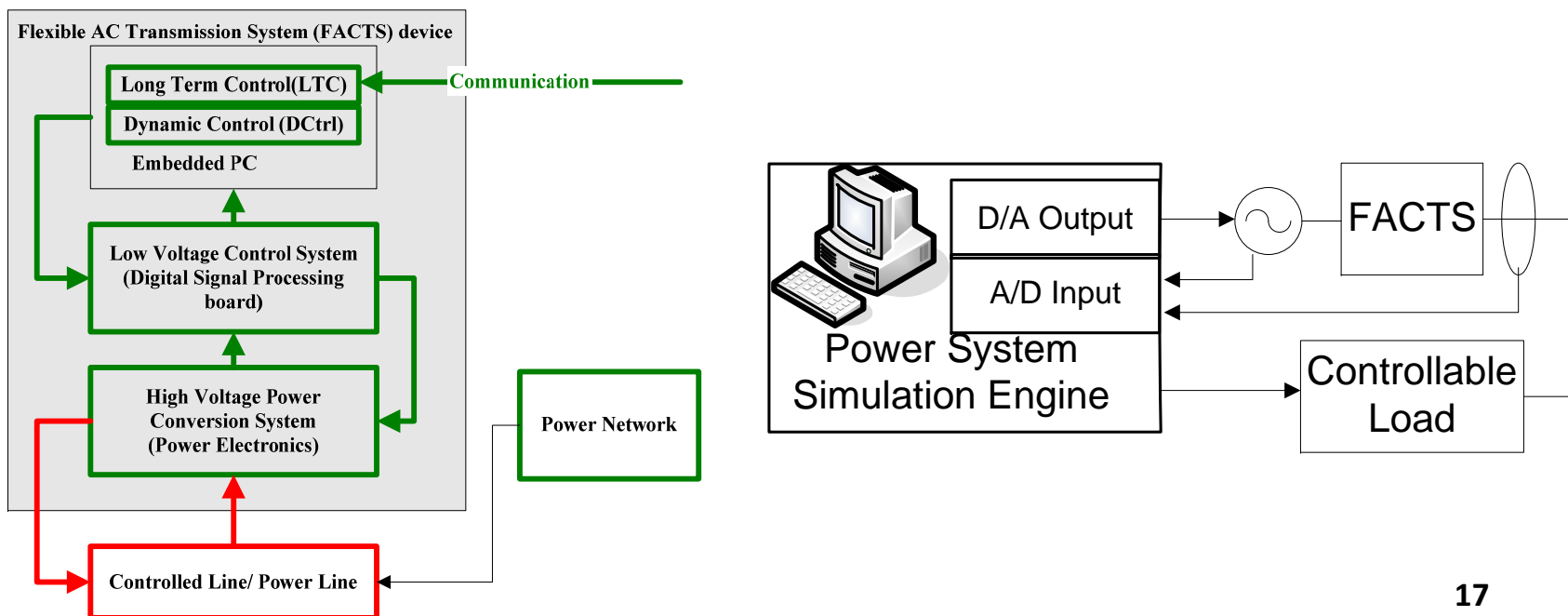
# Distributed Control

- Each power electronics subsystem contributes to the overall system operation.
- Previous work showed the sensitivity of the system to the controllers
  - Failed or compromised controllers can cause serious power system failures
- Cyber and physical interactions cause new vulnerabilities:
  - Frequency domain interactions
  - Confidentiality interactions

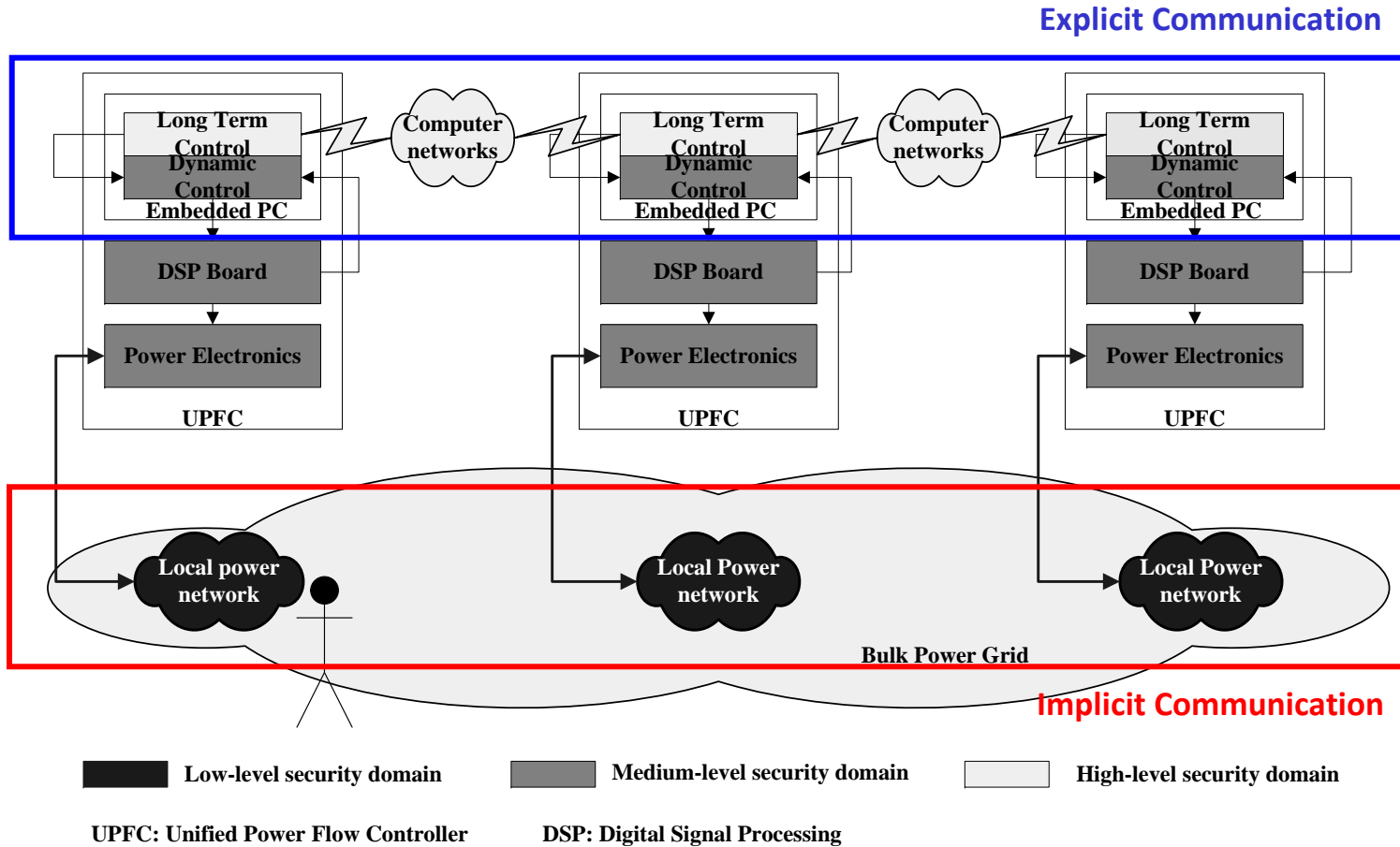


# FACTS Interaction Laboratory

- **FACTS Interaction Laboratory**
  - Real FACTS Devices and Programmable Load
  - Real-Time Simulated Large Power System



# Information Flow



# Information Flow Security in CPS

- **The physical nature of a security boundary tends to expose information outside the cyber world.**
- **The timing pattern could expose high-level system behaviors since time is global and can be observed by all the security levels.**

# Summary

- **UPQC – Provides a bidirectional ac-ac interface between the bulk power system and distributed energy resources**
- **DIC – Provides long and short-term energy storage capabilities to improve performance in both the bulk and distributed systems**
- **CPS – Determines and mitigate vulnerabilities in power electronic based systems in the bulk power grid**

# Special Thanks

- **Imre Gyuk - DOE**
- **Stan Atcitty - Sandia National Laboratories**
- **John Boyes - Sandia National Laboratories**