WEBINAR:
Real-time Simulation for De-Risking Energy Storage Integration

RTDS Technologies

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AGENDA

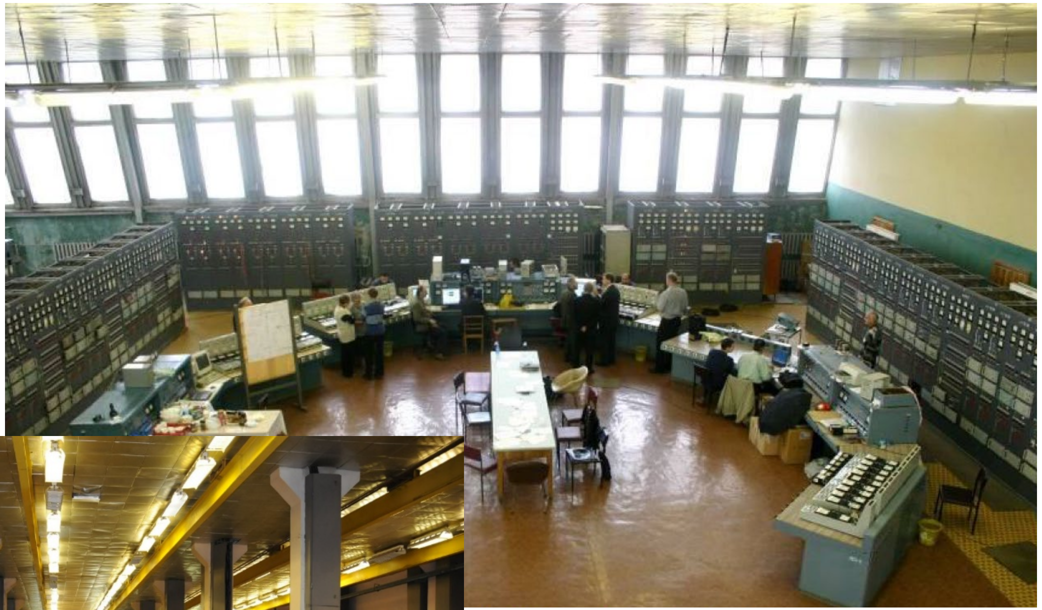
- History and introduction to the technology
- Hardware and software overview
- Energy storage background and modelling capabilities
- Demonstration in RSCAD
- Q&A

RTDS TECHNOLOGIES - THE COMPANY

- Based in Winnipeg, Canada
- ~80 employees
- World pioneer of real-time simulation and exclusive supplier of the RTDS Simulator
- Representatives in over 50 countries
- Hardware and software development, model development, customer support, sales and marketing, finance, product assembly and testing all under one roof

HISTORY OF REAL-TIME SIMULATION

- **1986**
  RTDS development project begins
- **1989**
  World's 1st real-time digital HVDC simulation
- **1993**
  1st commercial installation
- **1994**
  RTDS Technologies Inc. created



WORLDWIDE USER BASE

WORLDWIDE USER BASE

SIEMENS

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

ABB

UNSW
THE UNIVERSITY OF NEW SOUTH WALES

FLORIDA STATE UNIVERSITY
VIRES ARTES MORES
1851

SEL® SCHWEITZER ENGINEERING LABORATORIES

TU Delft

MANCHESTER
1824
The University of Manchester

APPLICATION AREAS

Distribution

- Microgrid testing.
- Renewables/DERs.
- Distribution automation.
- Inverter testing.

Power Electronics

- HVDC and FACTS.
- Energy conversion.
- Drives.

Smart Grid

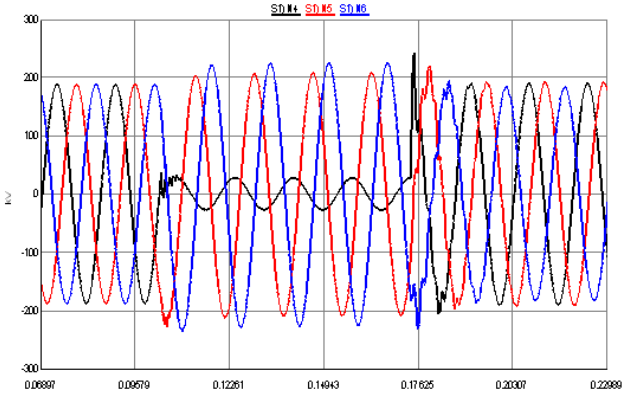
- Wide Area P&C testing.
- PMU studies.
- Cyber security.

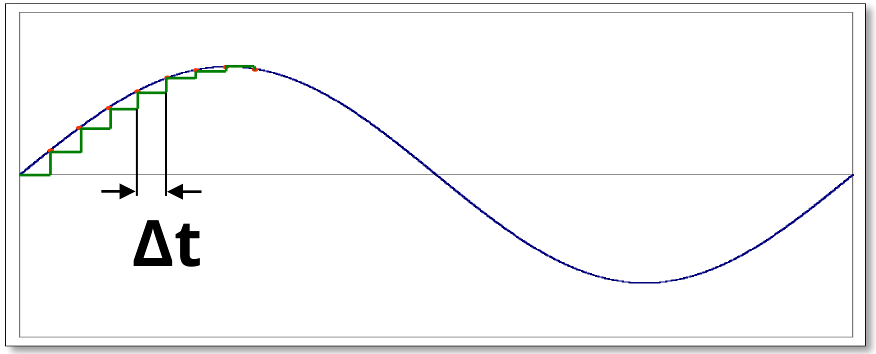
Protection

- Digital substations.
- Travelling wave testing.

WHAT IS EMT SIMULATION?

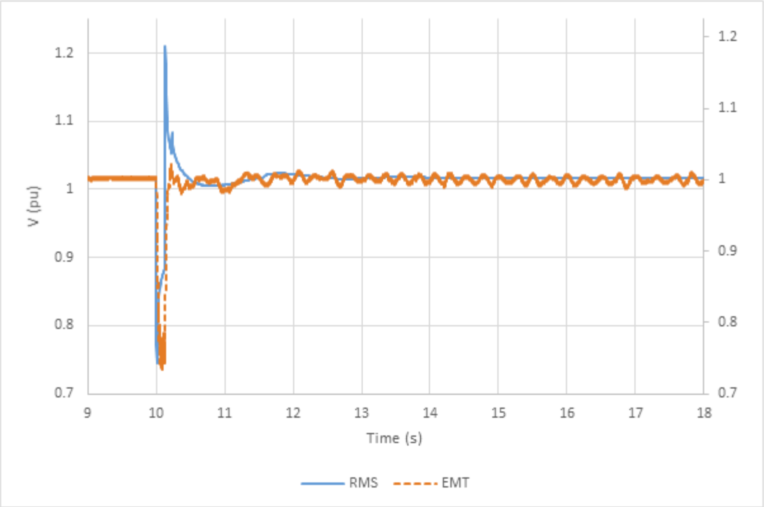
Type of Simulation	Load Flow	Transient Stability Analysis (TSA)	Electromagnetic Transient (EMT)
Typical timestep	Single solution	~ 8 ms	~ 2 - 50 μs
Output	Magnitude and angle	Magnitude and angle	Instantaneous values
Frequency range	Nominal frequency	Nominal and off-nominal frequency	0 – 3 kHz (<15 kHz)





ADVANTAGES OF EMT SIMULATION

- Allows for a greater depth of analysis than phasor domain (RMS) representations
- RMS models lack the ability to capture fast network dynamics during transient conditions and may provide optimistic results [1]
- Important for modern systems with many power electronic converters (more likely to predict control instability) [1]



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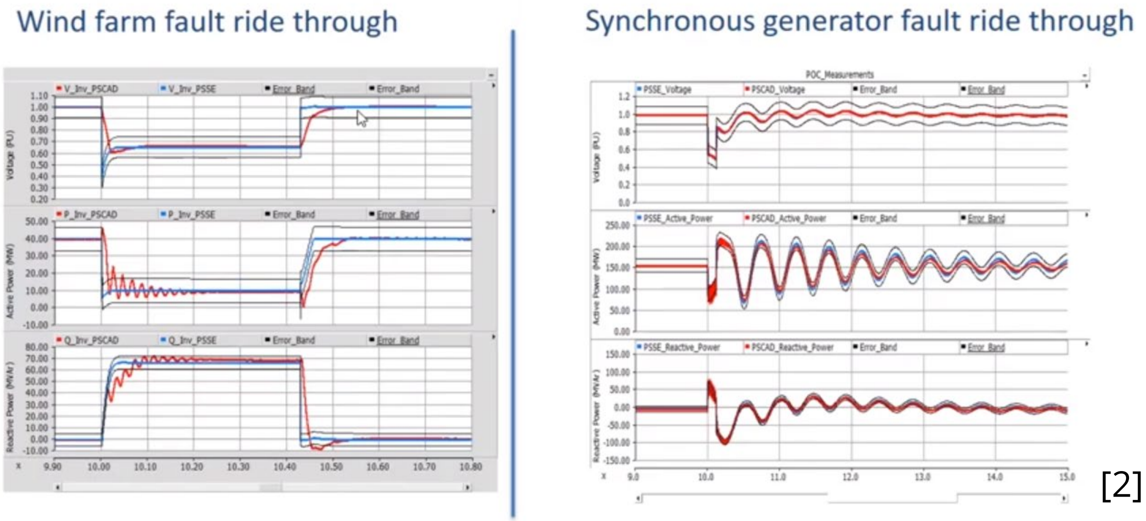


[2]

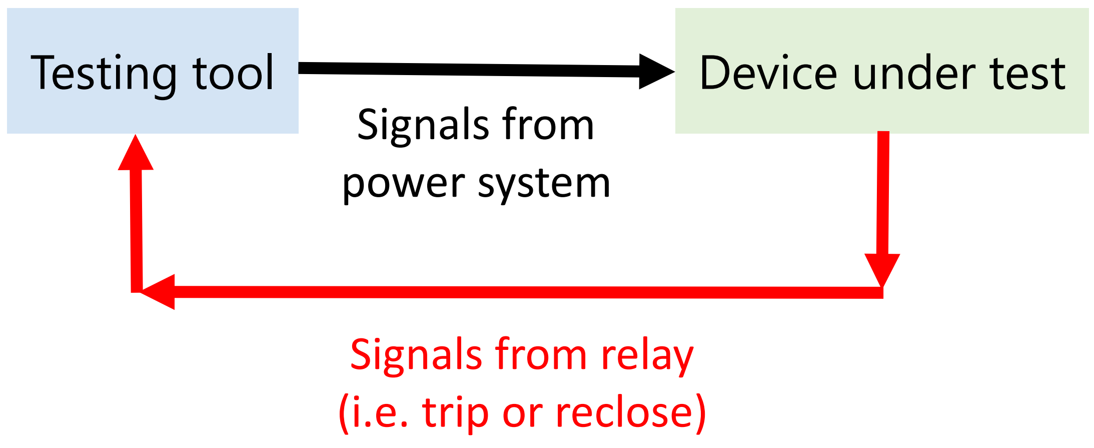
WHAT IS REAL TIME?

- **Real time it takes for an event to occur = Simulation time of an event.**
  - E.g. 3 cycle fault for 60Hz system = 0.05 seconds. RTDS simulates this fault in real time i.e. 0.05 seconds
  - Non-real-time simulations will simulate events faster or slower than real time depending on case complexity
- **Values updated each timestep**
  - All calculations and servicing I/O completed within a timestep.
  - Every timestep has same duration and is completed in real time
- **Requires dedicated parallel processing hardware**

ADVANTAGES OF CLOSED-LOOP (HIL) TESTING

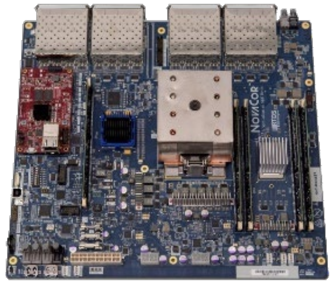
Real time operation is what allows us to connect physical devices in a **closed loop** with the simulated environment <u>**(hardware-in-the-loop HIL)**</u>

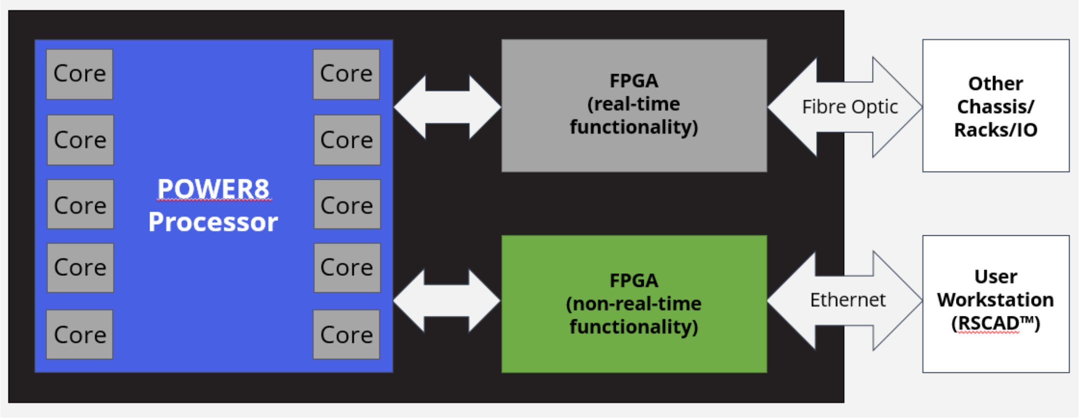
- Test continues after the action of the protection/control device, showing dynamic response of the system
- Test multiple devices (and entire schemes) at once
- Much more detailed system representation than open-loop test systems provide (e.g. modelling power electronics)
- No need to bring equipment out of service



HARDWARE REQUIRED FOR REAL-TIME SIMULATION AND HIL TESTING

Parallel processing hardware

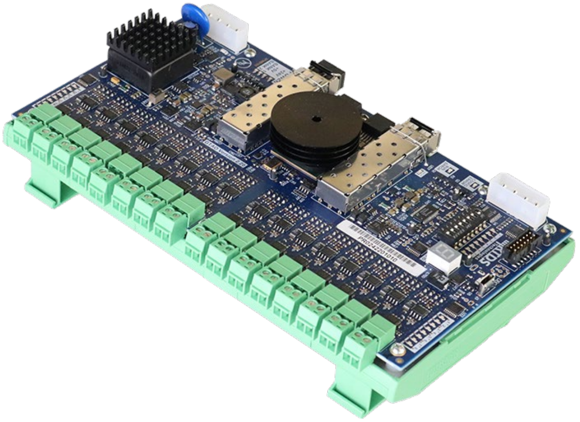




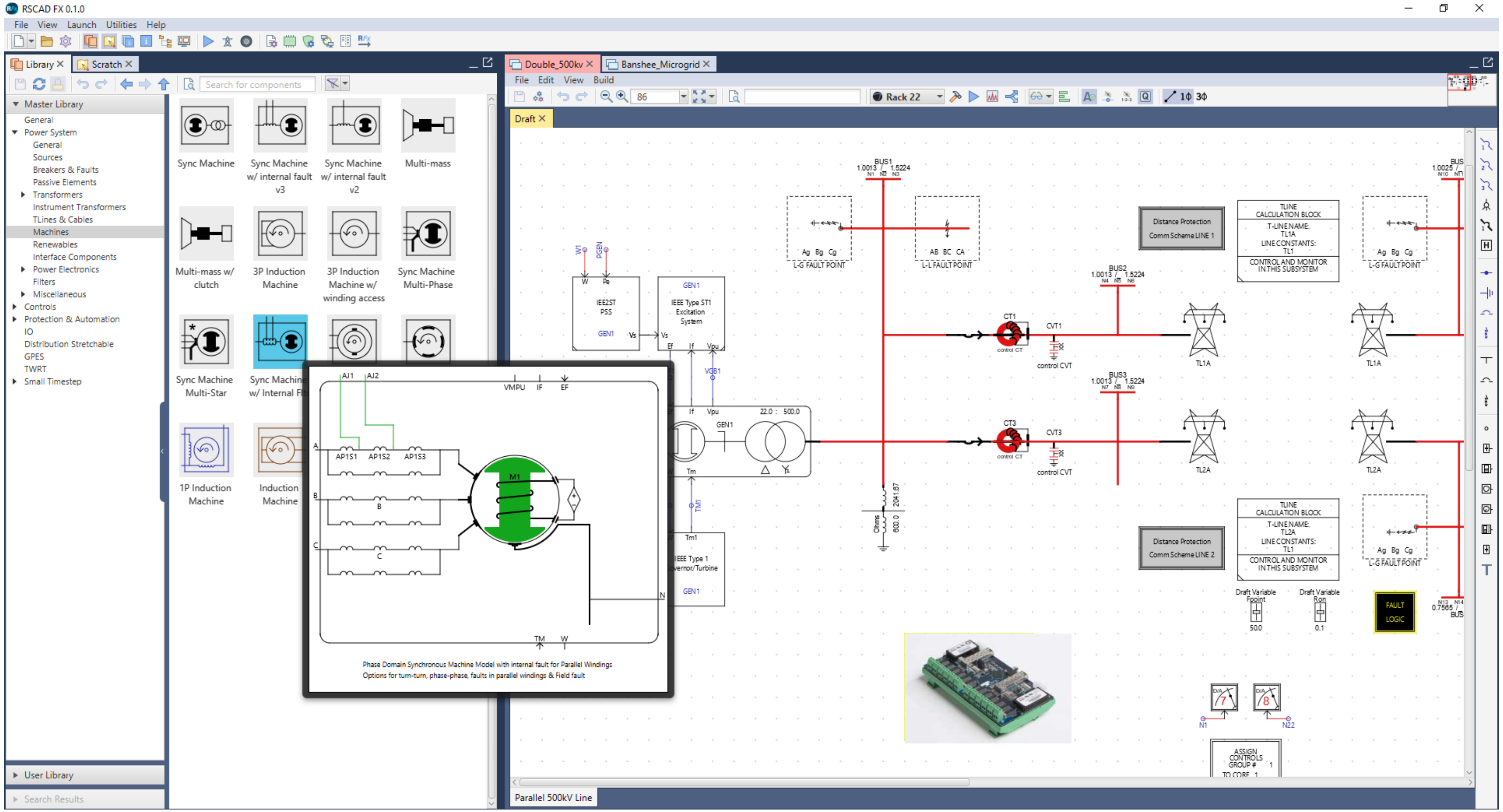
Input/output devices

Communication protocol based

Analogue/digital

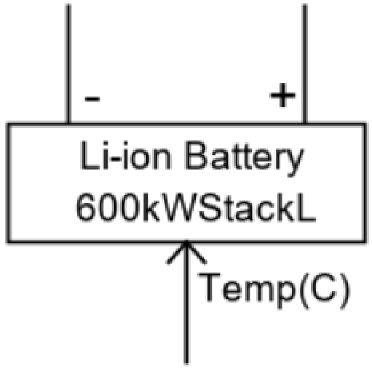


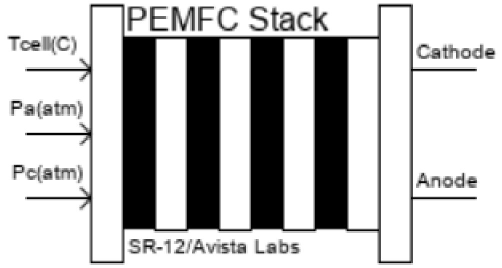
REAL-TIME SIMULATION SOFTWARE: RSCAD FX

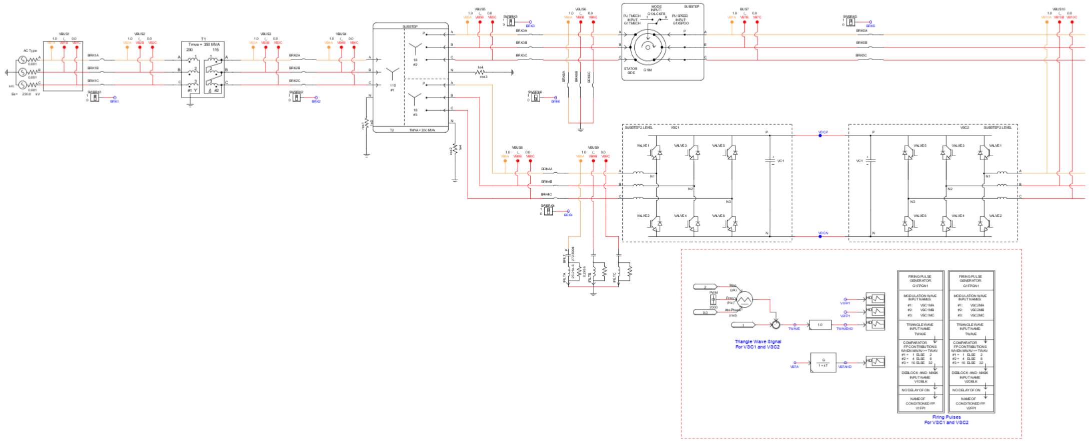


ENERGY STORAGE MODELLING

- Energy storage
  - PEM fuel stack model
  - Battery energy storage systems
    - Lithium ion battery model
    - Input for temperature
  - Flywheel sample case
    - Wheel modelled via added mass to PMSM rotor
    - Average model case also available
  - Pumped hydro sample case
    - Variable-speed DFIM system
    - Average model case also available



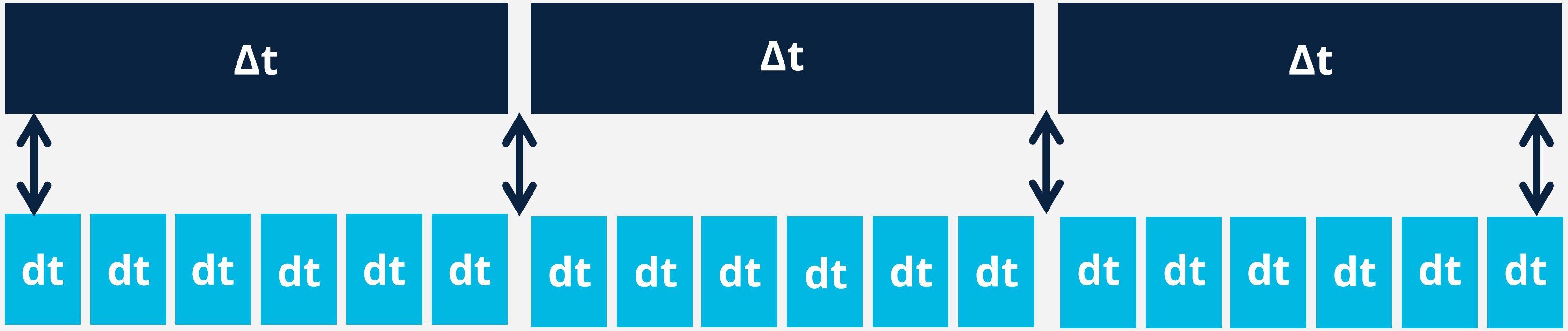




CONVERTER MODELLING OPTIONS

Converter models are run on the main RTDS Simulator processing hardware (no FPGA required)

Mainstep
Δt



Average models

Substep
dt = Δt ÷ n

Fully-switched models

NEW OPTION: Universal Converter Model (UCM)

- Switching function state space model
- Can be used in Mainstep or Substep environment
- Accurately represent switching >100 kHz
- Switch at ~3 kHz at ~30-50 us: huge computational savings

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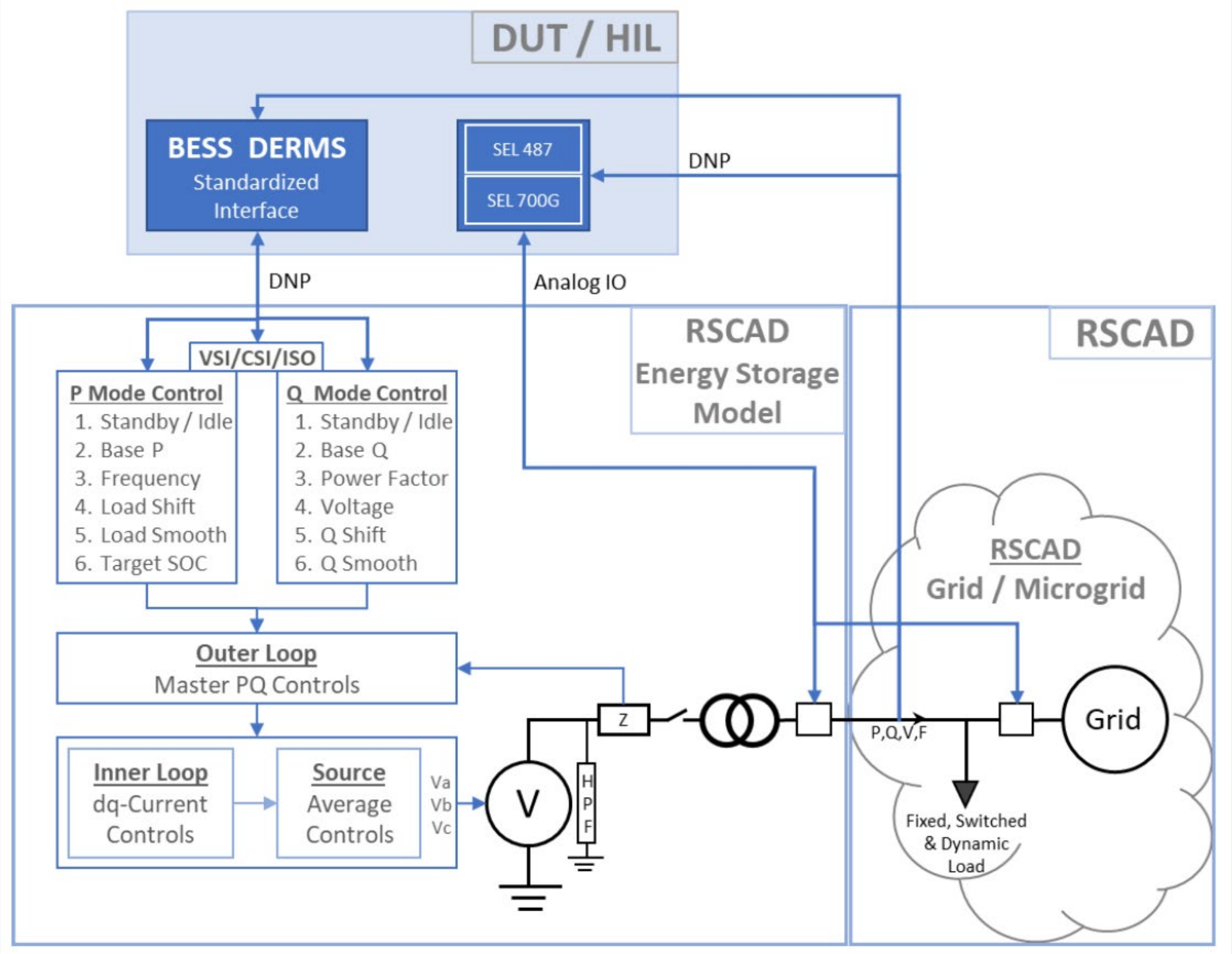
Wednesday June 30, 2021 – 9 AM CST
Visit www.rtds.com to register

UTILITY PROJECT EXAMPLE: BATTERY INTEGRATION

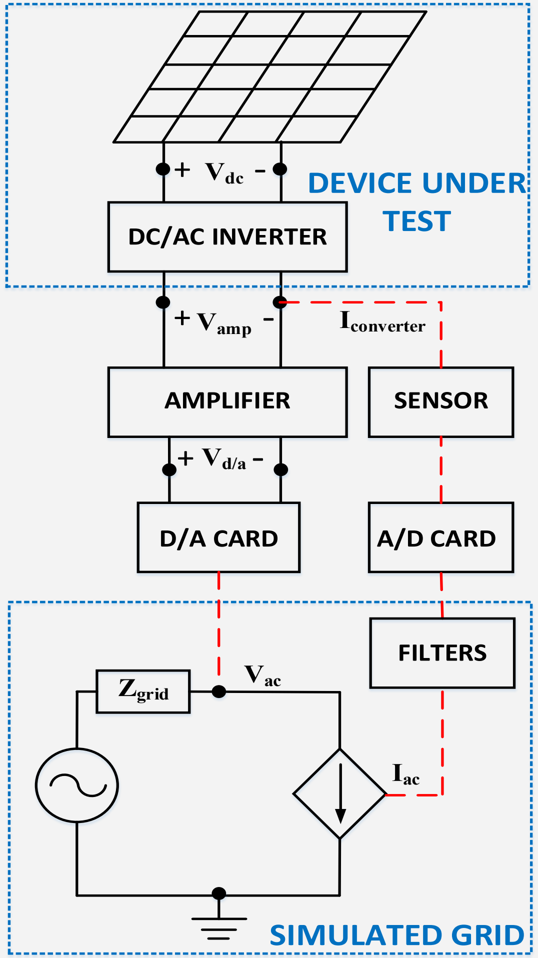
San Diego Gas & Electric

- Testbed for BESS integration
- Validate functional behaviour, coordination with DERMS, and effects on local protection



POWER HARDWARE IN THE LOOP (PHIL)

- Simulated environment exchanges power with renewable energy hardware, motors, batteries, loads, etc.



Thank you!

You can contact me at
kati@rtds.com

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Real Time Simulation for De-Risking Energy Storage Integration

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AGENDA

- **Introduction**
  - Fundamentals, Types and Applications of Energy Storage Systems
- **Modeling Energy Storage Systems**
  - Batteries
  - Flywheels
  - Pumped Hydro
- **Energy Storage Case Demonstrations**
- **Questions and Answers**.

Introduction

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Fundamentals of Energy Storage

- Electric Energy is converted and stored from one form to the other.
    - Fossil Fuels (Coal, Oil, Natural Gas)
    - Hydro Electric Dams.
    - Renewable Energy (Wind and Solar)



Types of Energy Storage

Mechanical
- Pumped Hydro
- Combustion Engines
- Flywheels

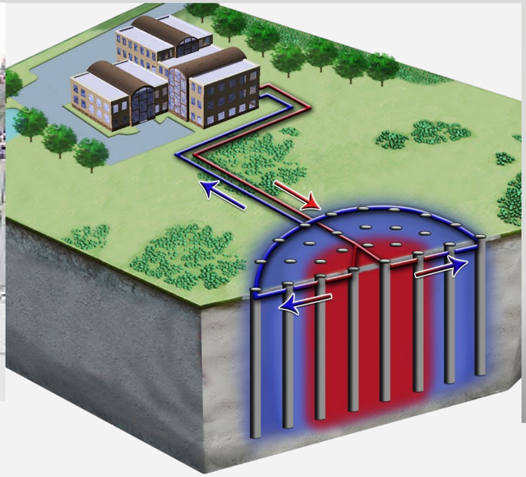
Electrochemical
- Batteries
- Fuel cells

Thermal
- Molten Salt
- Geothermal

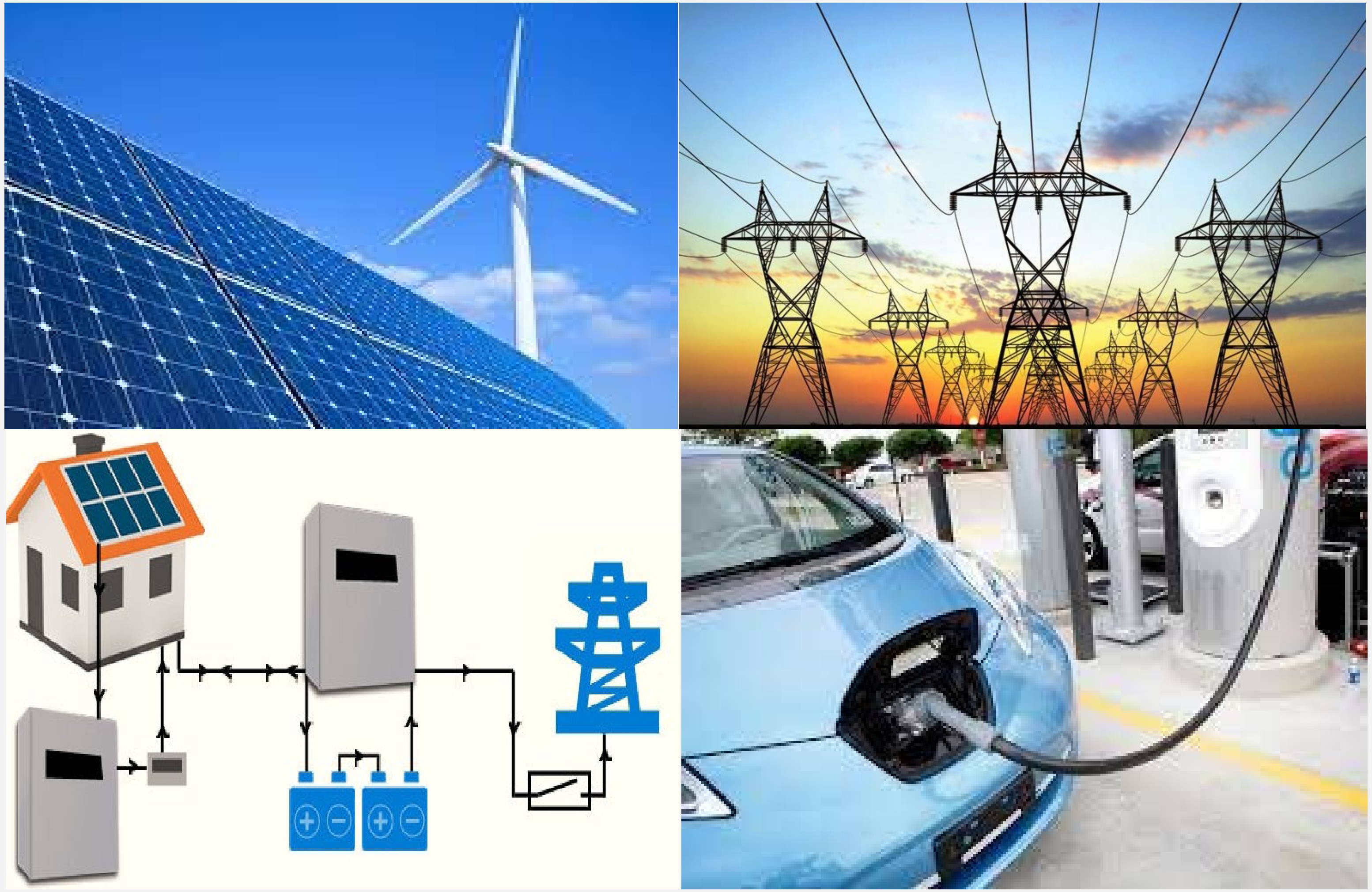
Chemical/Biochemical
- Biomass
- Methane








Applications of Energy Storage



Fundamentals of Energy Storage

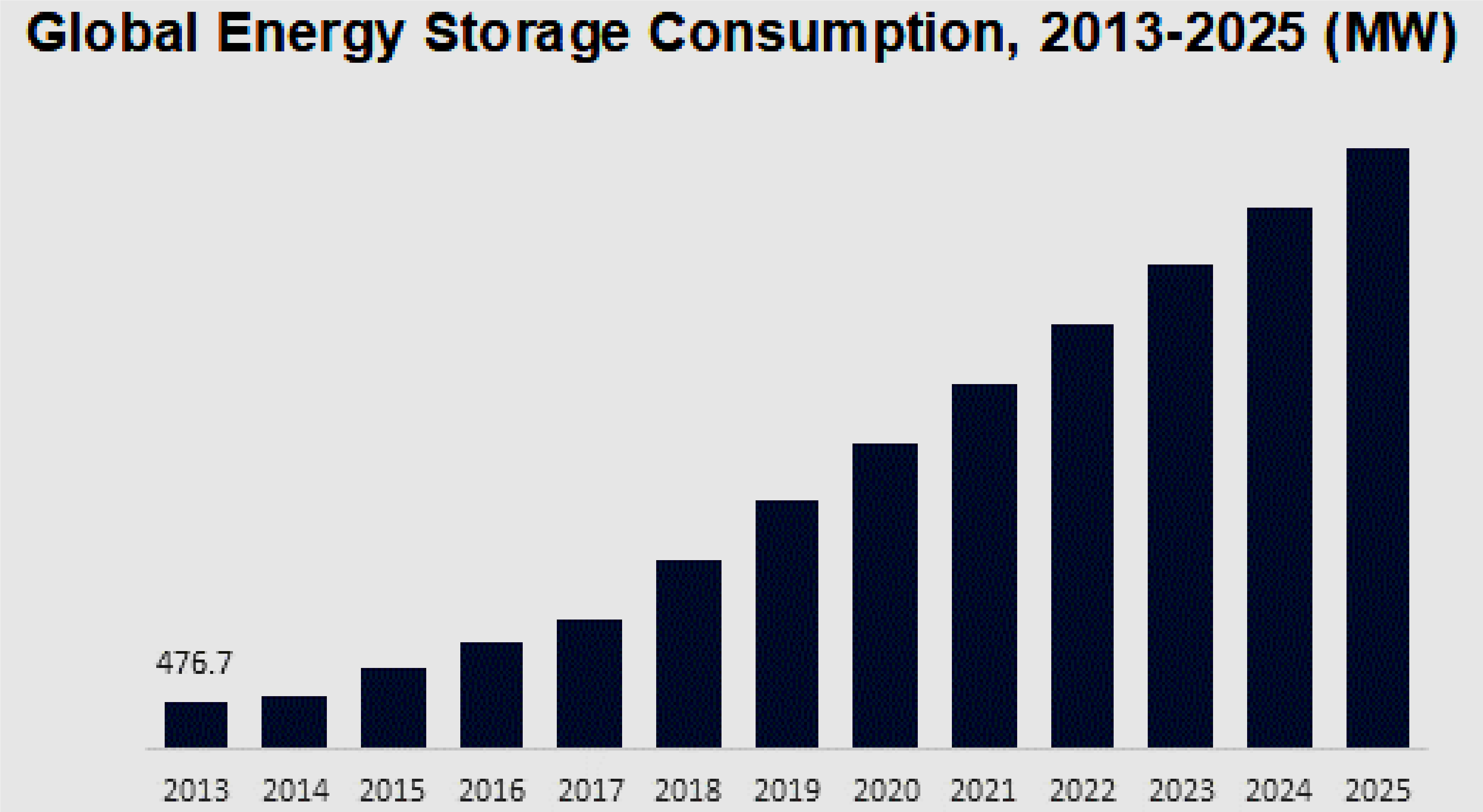


Image Reference: Adroit Market Research

Modeling Energy Storage Systems

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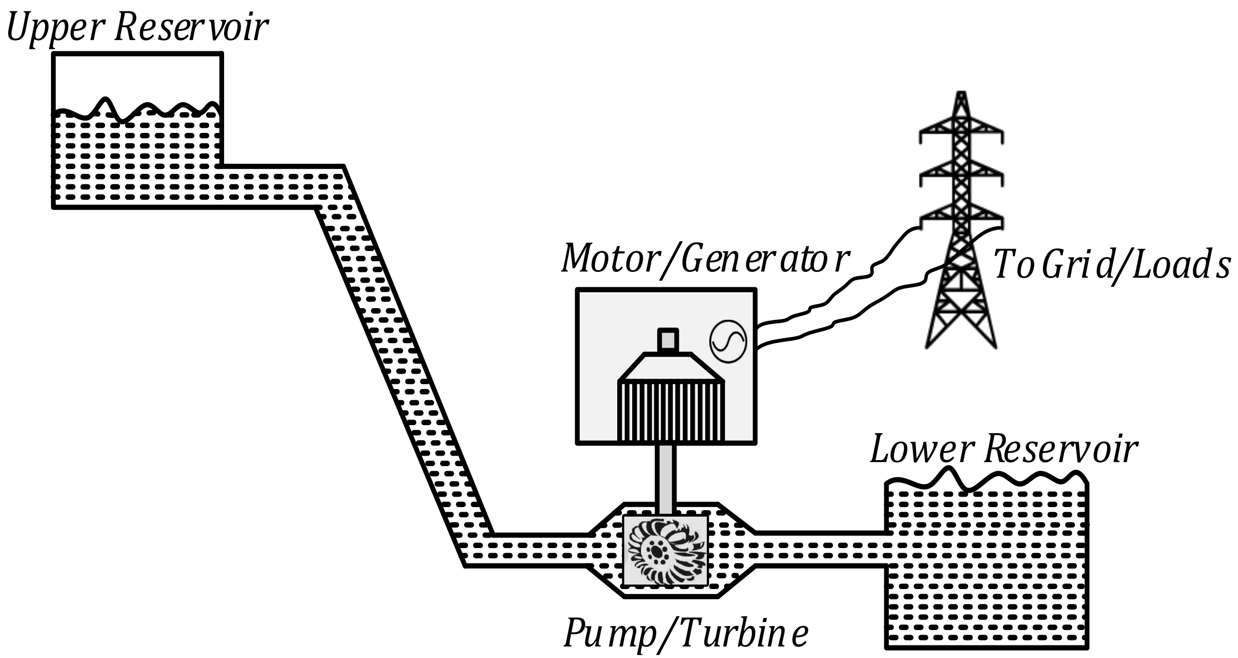
Pumped Hydro Storage (PHS)

- Most mature and widespread method for large-scale electricity storage. Contributes over 95% of global energy storage capacity

Image Credit: Consumers Energy/CMS Energy



- Stores/generates electricity by moving water between reservoirs at different elevations.

Pumped Hydro Storage: Benefits and Drawbacks

Benefits

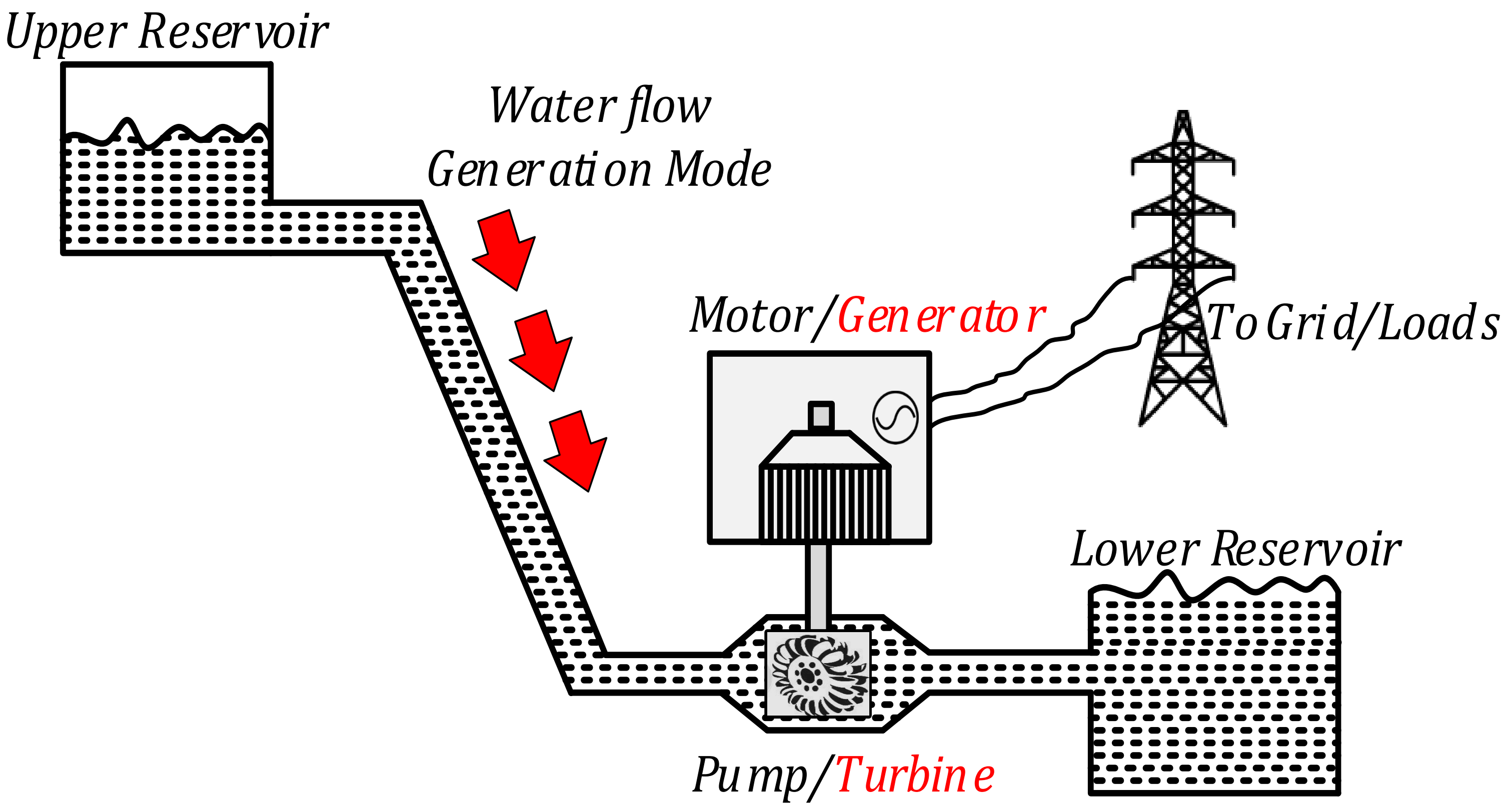
- PHS provide bulk energy storage for locations where large conventional hydro systems are not viable.
- PHS provide fast load and energy balancing, black start grid capability and reactive power support.
- PHS have high operating efficiencies (70% - 80%) and life cycles over 50 years.

Drawbacks

- Technical requirements for PHS operation include a sufficient amount of water and elevation between the reservoirs to allow smaller pump/turbine units and reduced system losses.
- PHS require access to reliable transmission networks for power supply to grid/loads.
- PHS have high capital investment costs

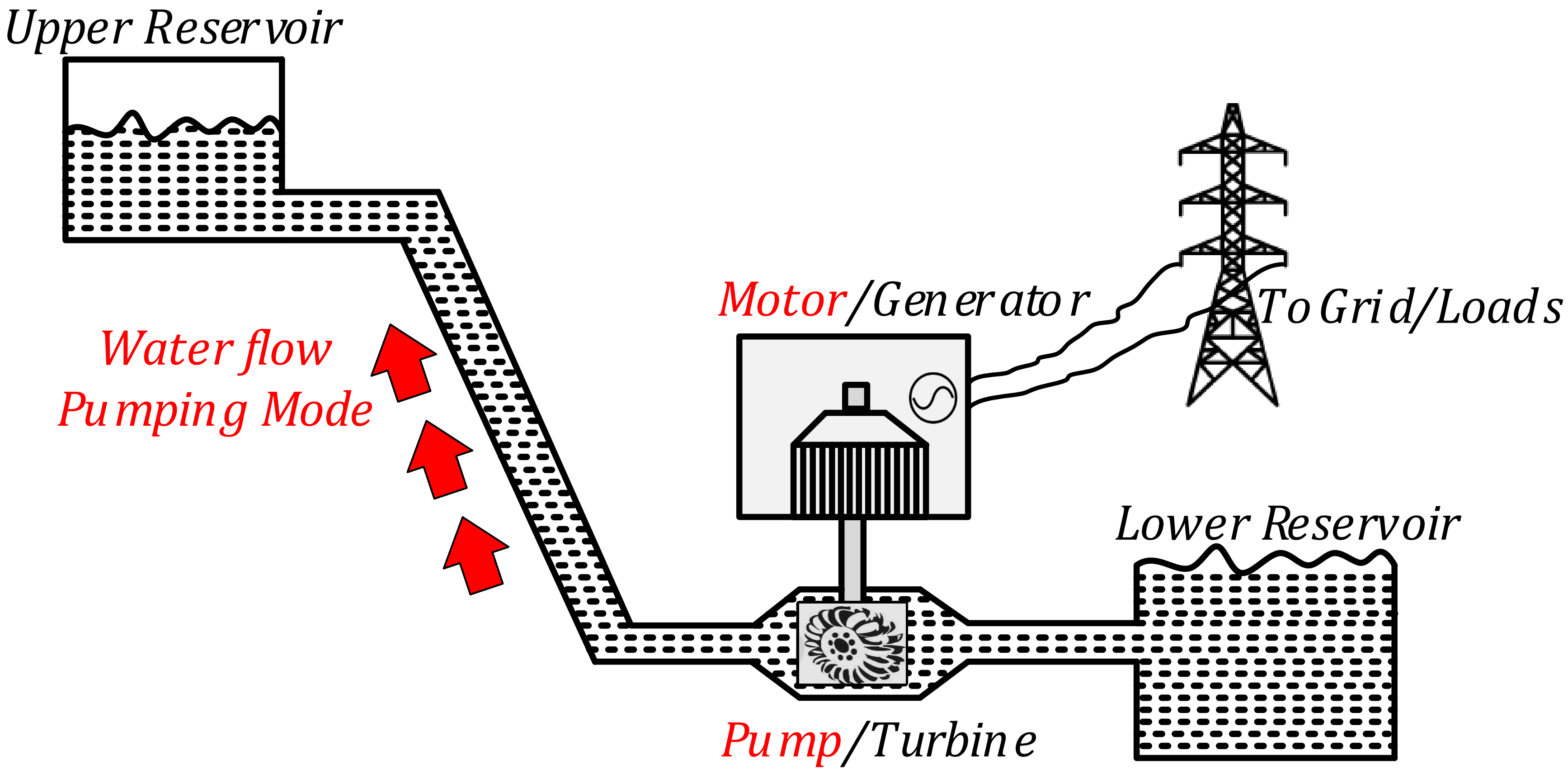
PHS Operation

- **Generation Mode: Generator/Turbine Operation**



PHS Operation

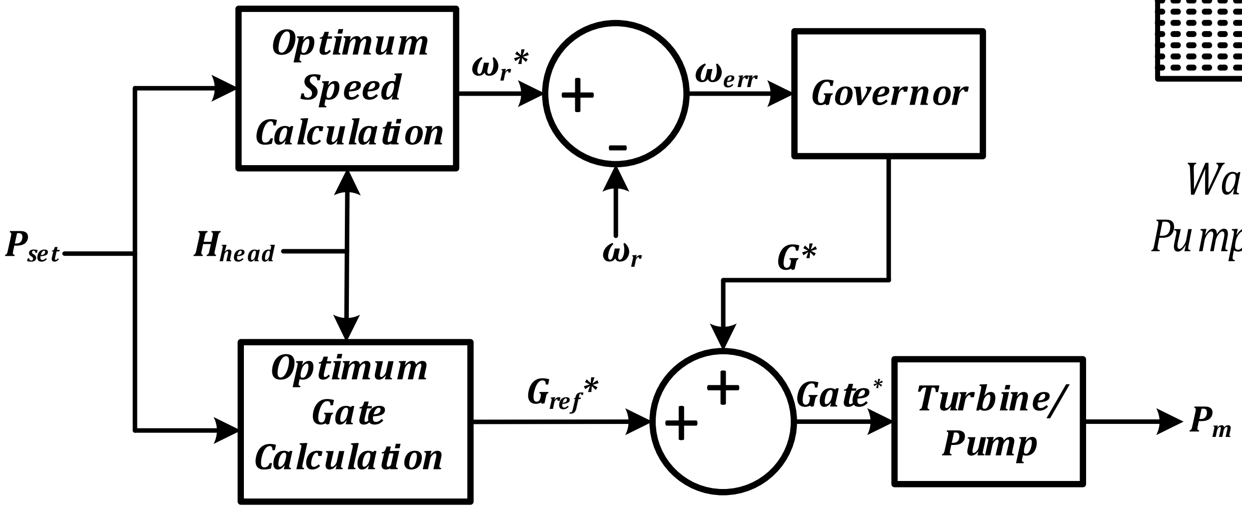
- **Pumping Mode: Motor/Pump Operation**

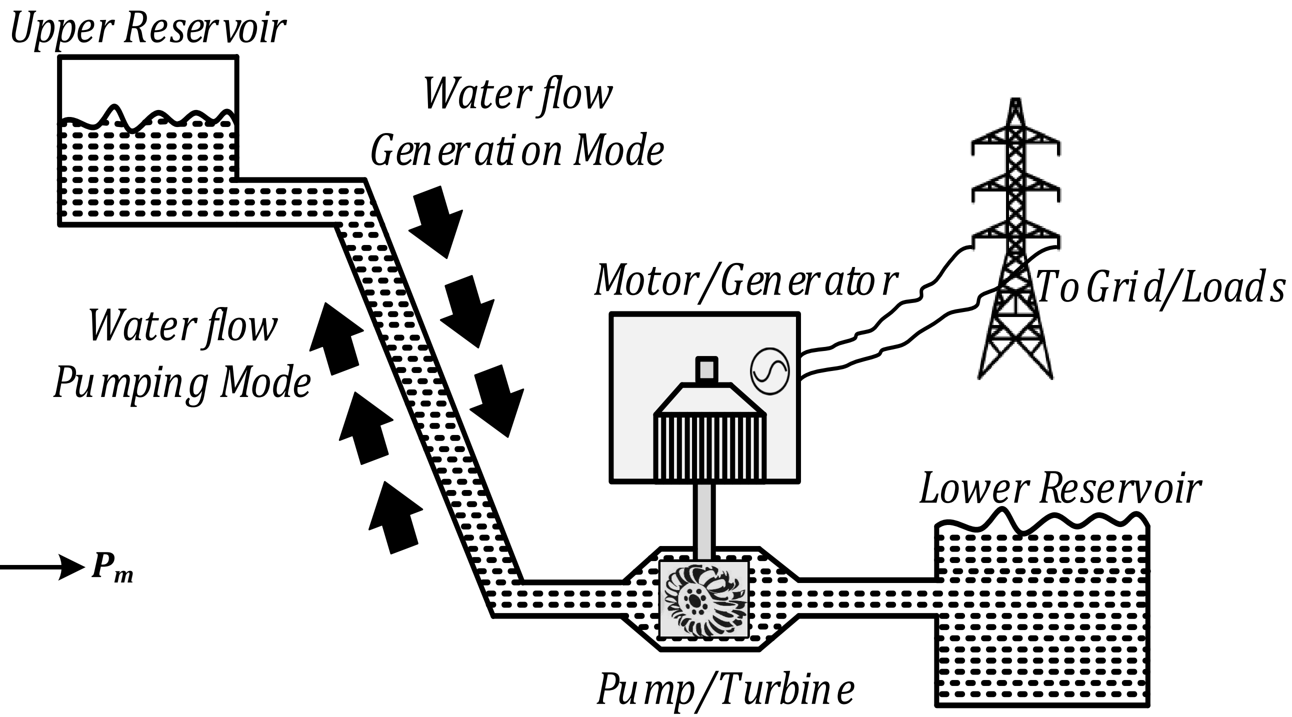


PHS Operation

Pump and Turbine Controls

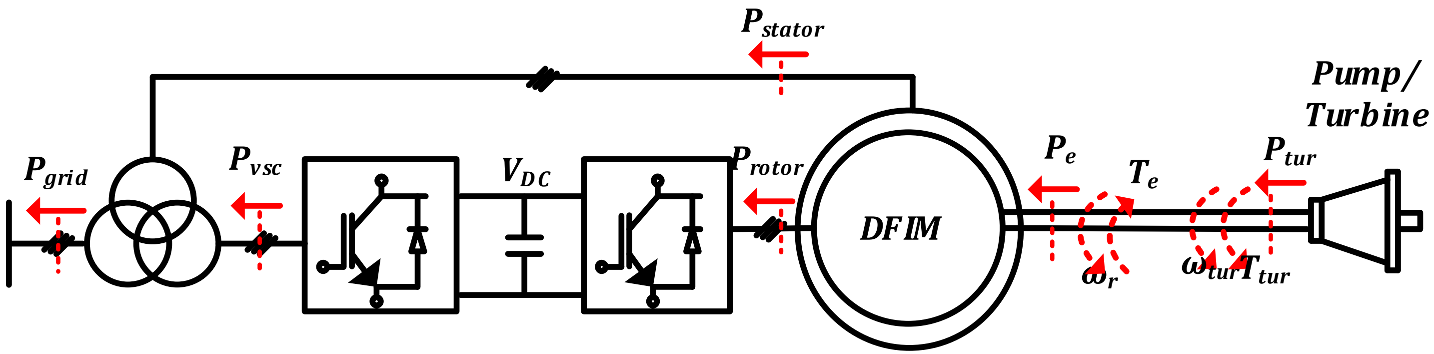
- Regulates the water flow by adjusting the speed and gate position for a given water head (height between reservoirs).



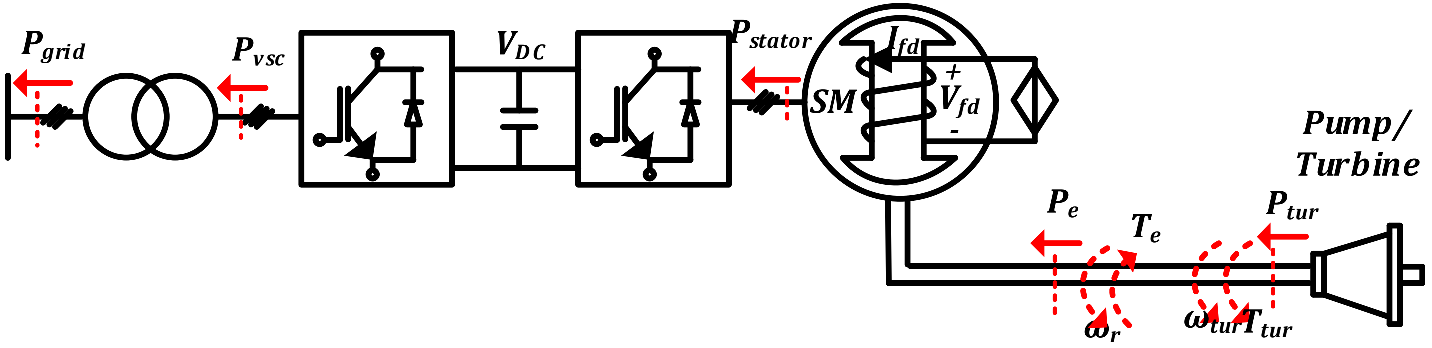


PHS Operation: Variable Speed Converters

- **Double Fed Induction Machines (DFIM)**
  - Lower converter ratings.
  - Suited for High Power Applications (>100MW)



- **Full Converter-Fed Synchronous Machines (FCFSM)**
  - Well established SM technology.
  - Robust and high efficiencies.
  - Small to Medium Power Applications (< 100MW)

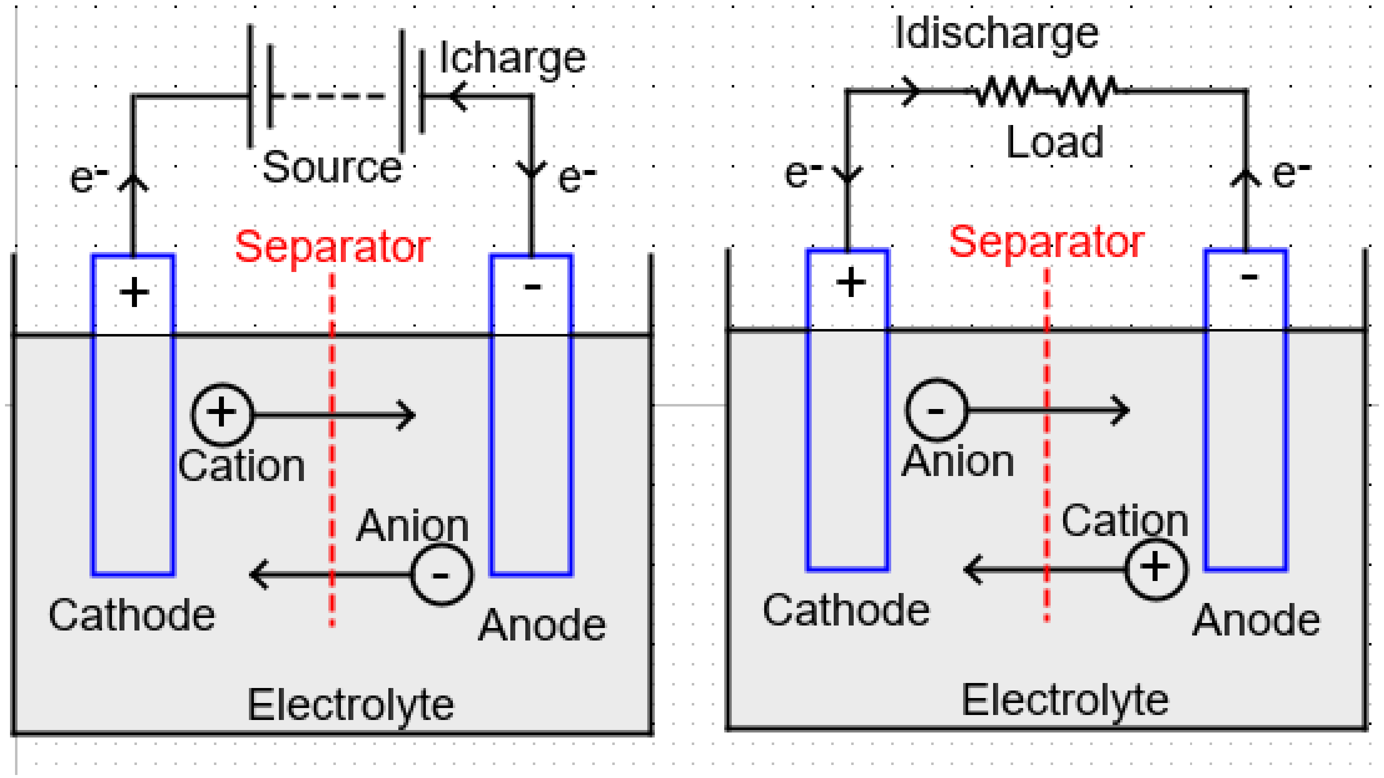


Battery Energy Storage Systems (BESS)

Image Credit: www.greentechmedia.com

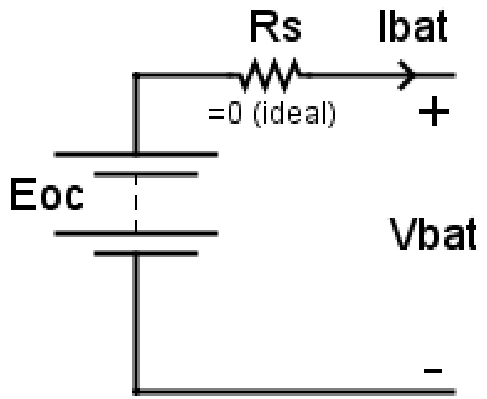
Battery Operation: Charging and Discharging

- Factors for BESS operation
  - State of Charge (SOC)
  - Battery Capacity (Ampere Hours)
  - Open circuit voltage (Eoc)
  - Charge/Discharge Cycle
  - Self Discharge rate
  - Battery age
  - Temperature dependence

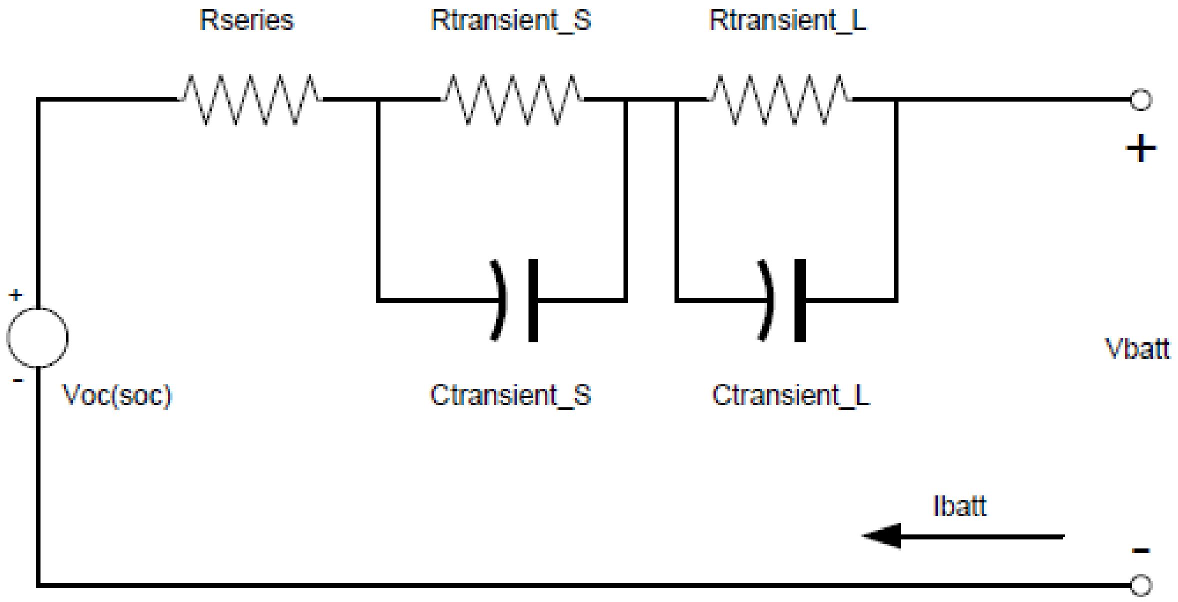


Battery Electric Circuit Model

- Detailed modeling of battery operating characteristics increases complexity of the simulation model



- Ideal/Simple Circuit Model



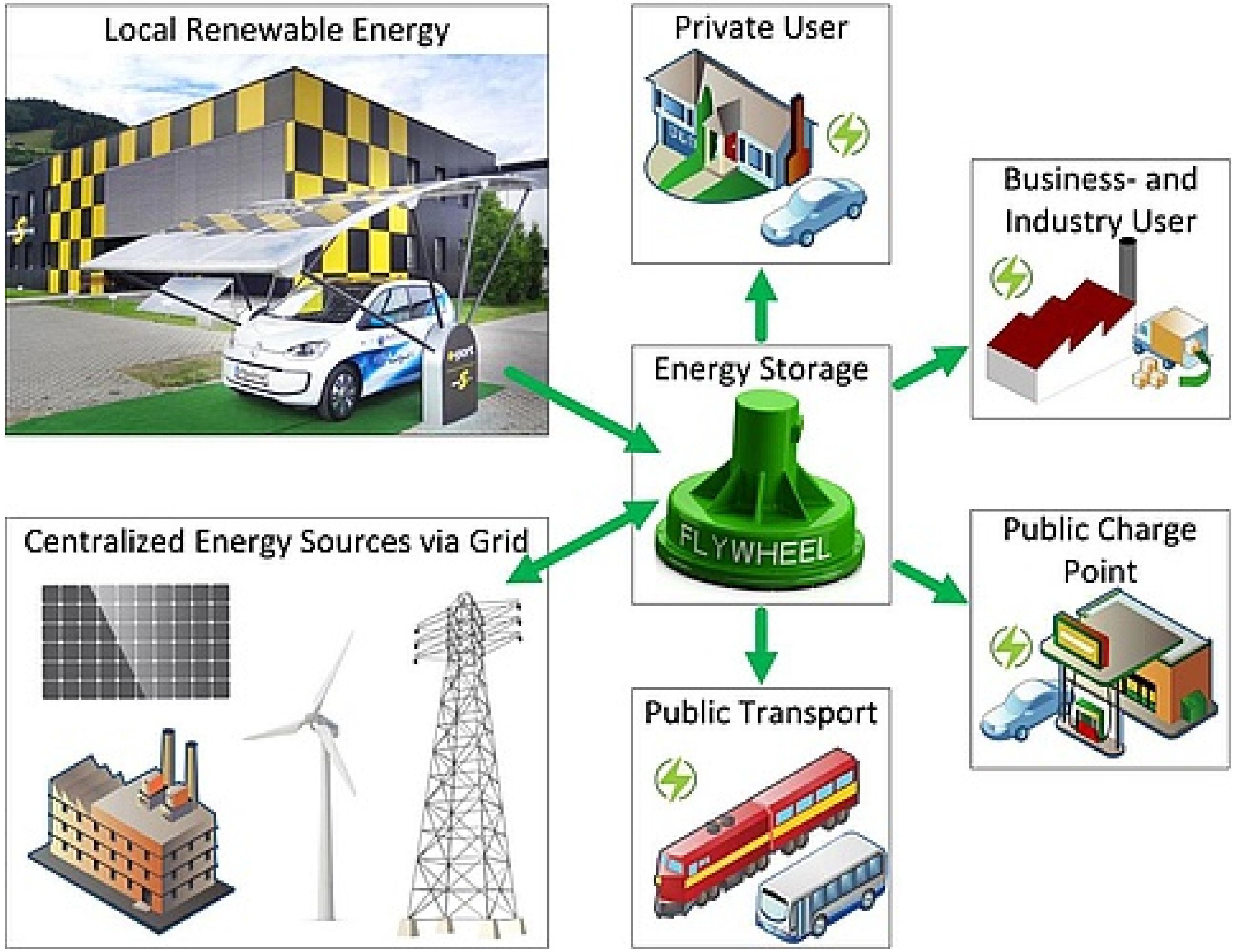
- Thevenin Circuit Model

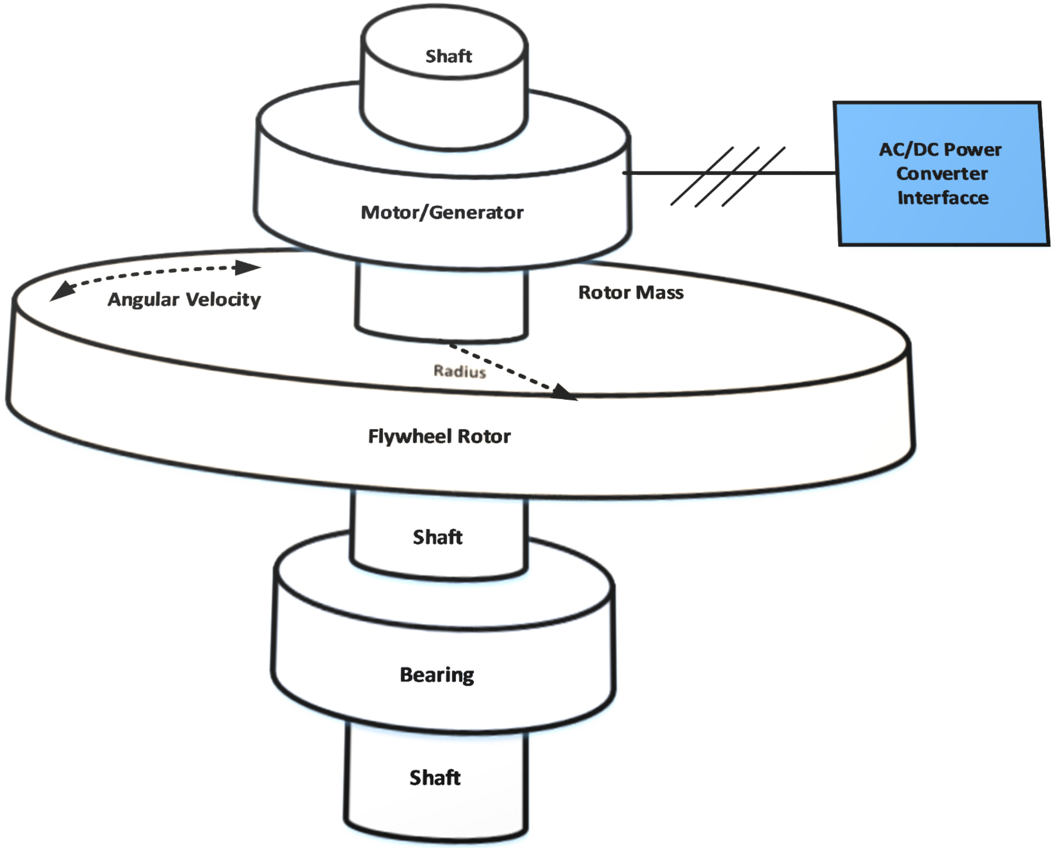
Battery Storage: Benefits and Drawbacks

- **Benefits**
  - High energy densities
  - Back up power for grid voltage support.
  - Flexible and customizable especially for on site customer storage and revenue generation

- **Drawbacks**
  - High Cost of Startup, Maintenance and Recycling
  - Limited life span 5-10 years
  - Dangerous chemicals and high risk of fire hazards

Flywheel Energy Storage Systems



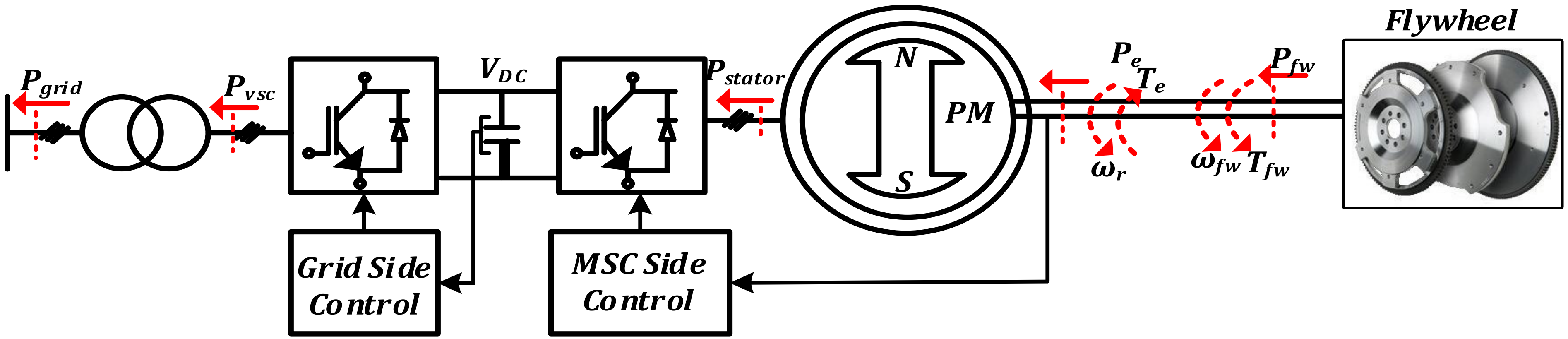


Flywheel Storage: Benefits and Drawbacks

- **Benefits**
  - Able to provide long discharge cycles for high energy capacity
  - Fast power, frequency and voltage control response.
  - Long design life spans 30 years
  - No chemicals and fire hazards like batteries
- **Drawbacks**
  - Flywheel storage capacity is size dependent creating space constraints.
  - Fixed installation due to nature of Flywheels.
  - Prone to mechanical stress and bearing failures

Flywheel Energy Storage: Configuration

- Typical Permanent Magnet Synchronous Machine drives used in Flywheels.



Real Time ElectroMagnetic Transient Models for Energy Storage and Renewable Applications

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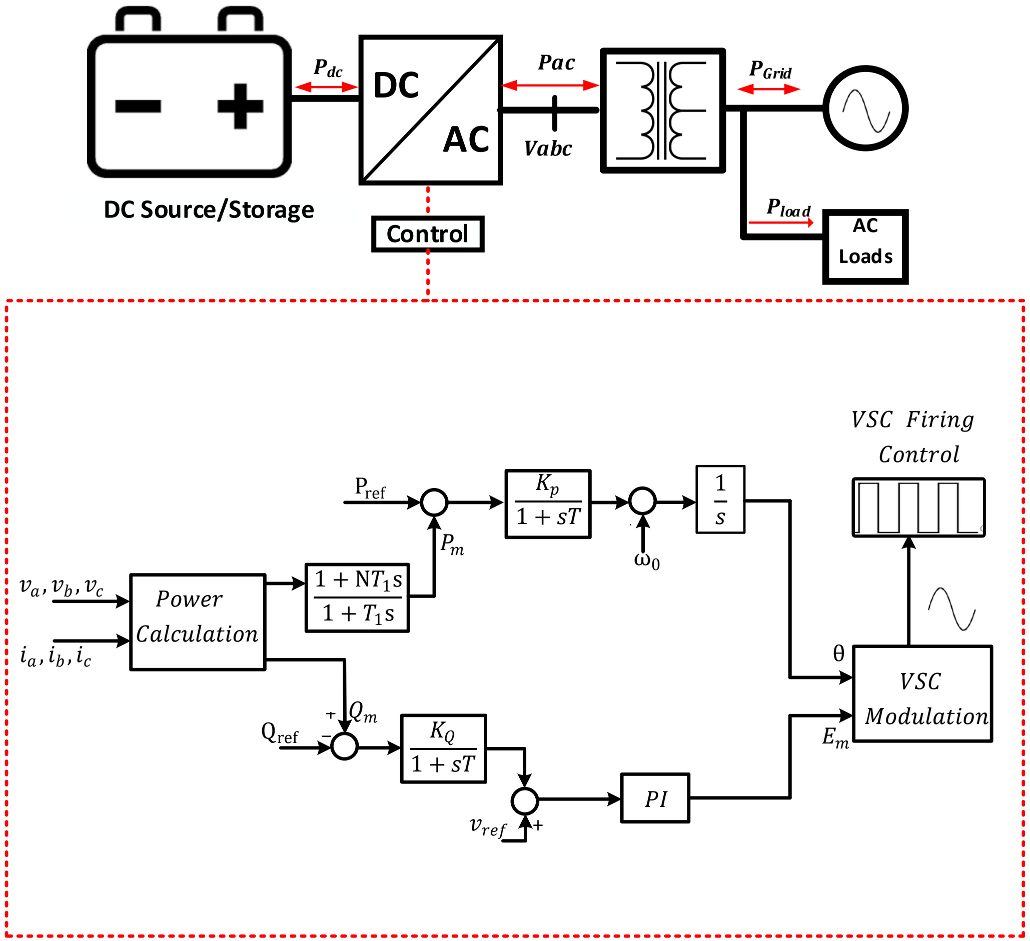
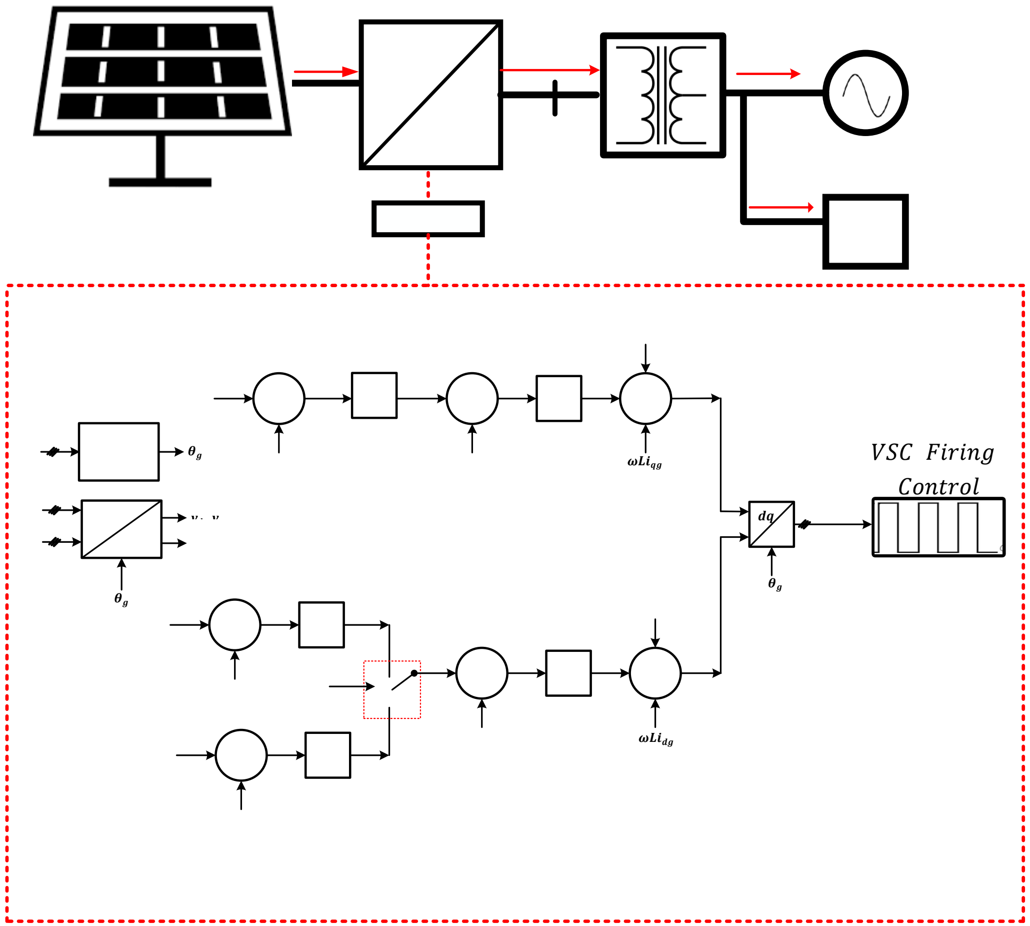
Control System Models

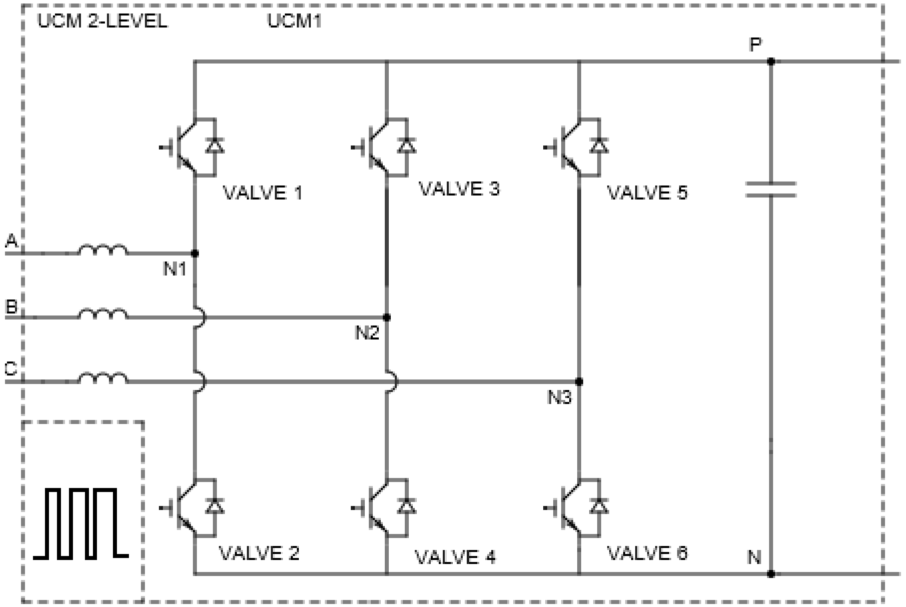


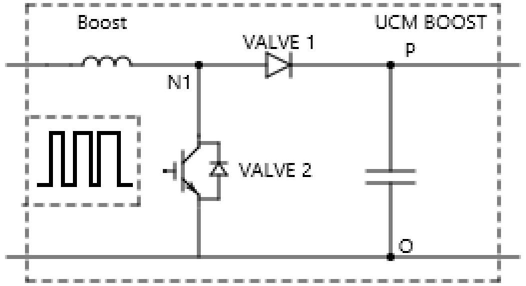


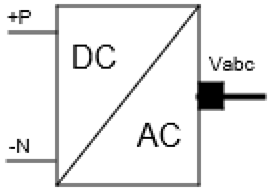
Power Converters Models

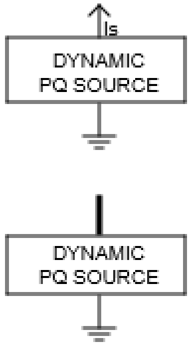
- Power Converter Models
  - Firing Pulse/Switched Models
  - Switching Function State Space Models
  - Dynamic Average Value Models
    - Dynamic PQ Source Model

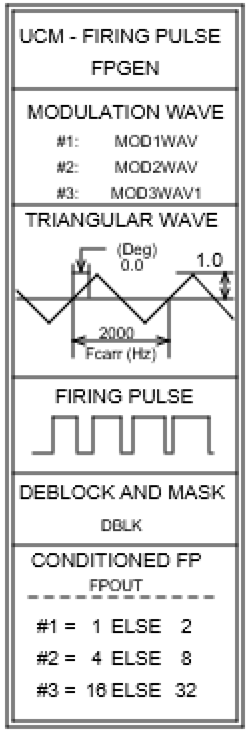
Power Converters Models



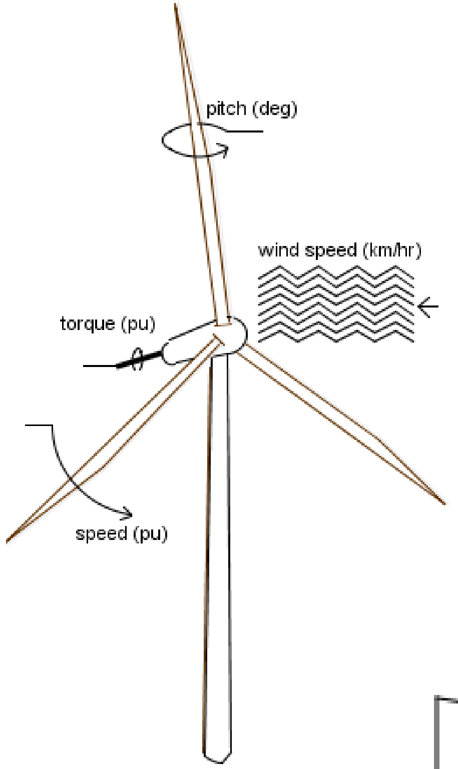


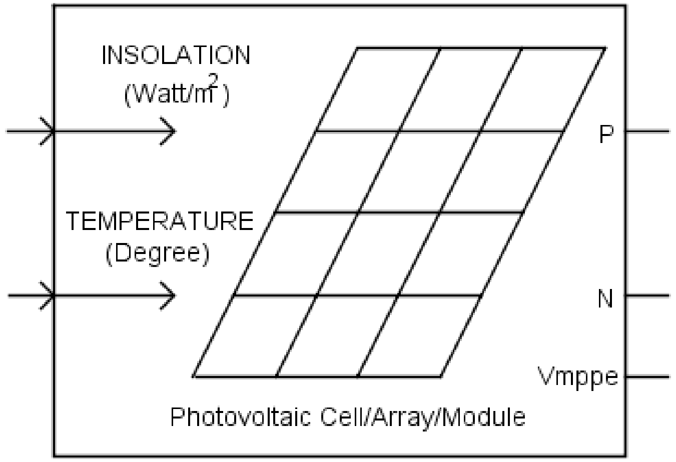


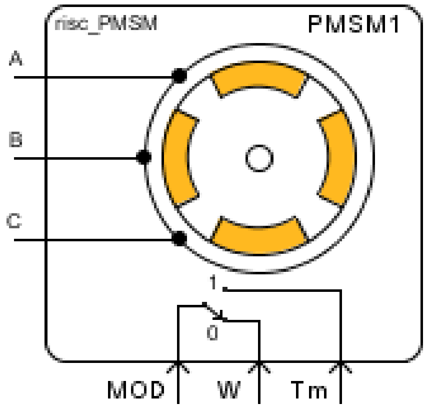


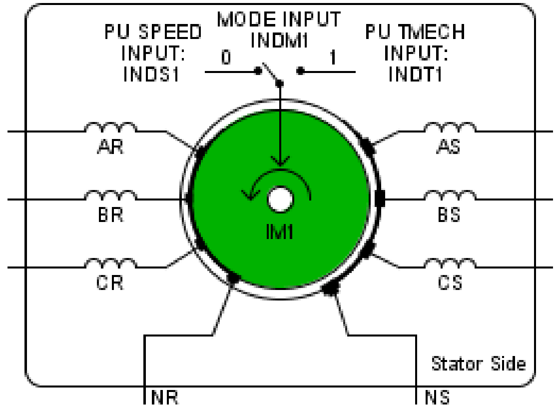


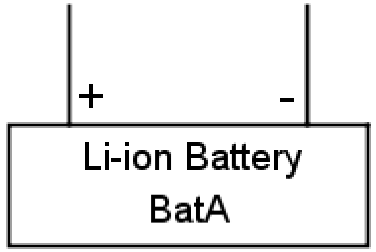
Energy Storage and Renewables Models











Energy Storage Case Demonstrations

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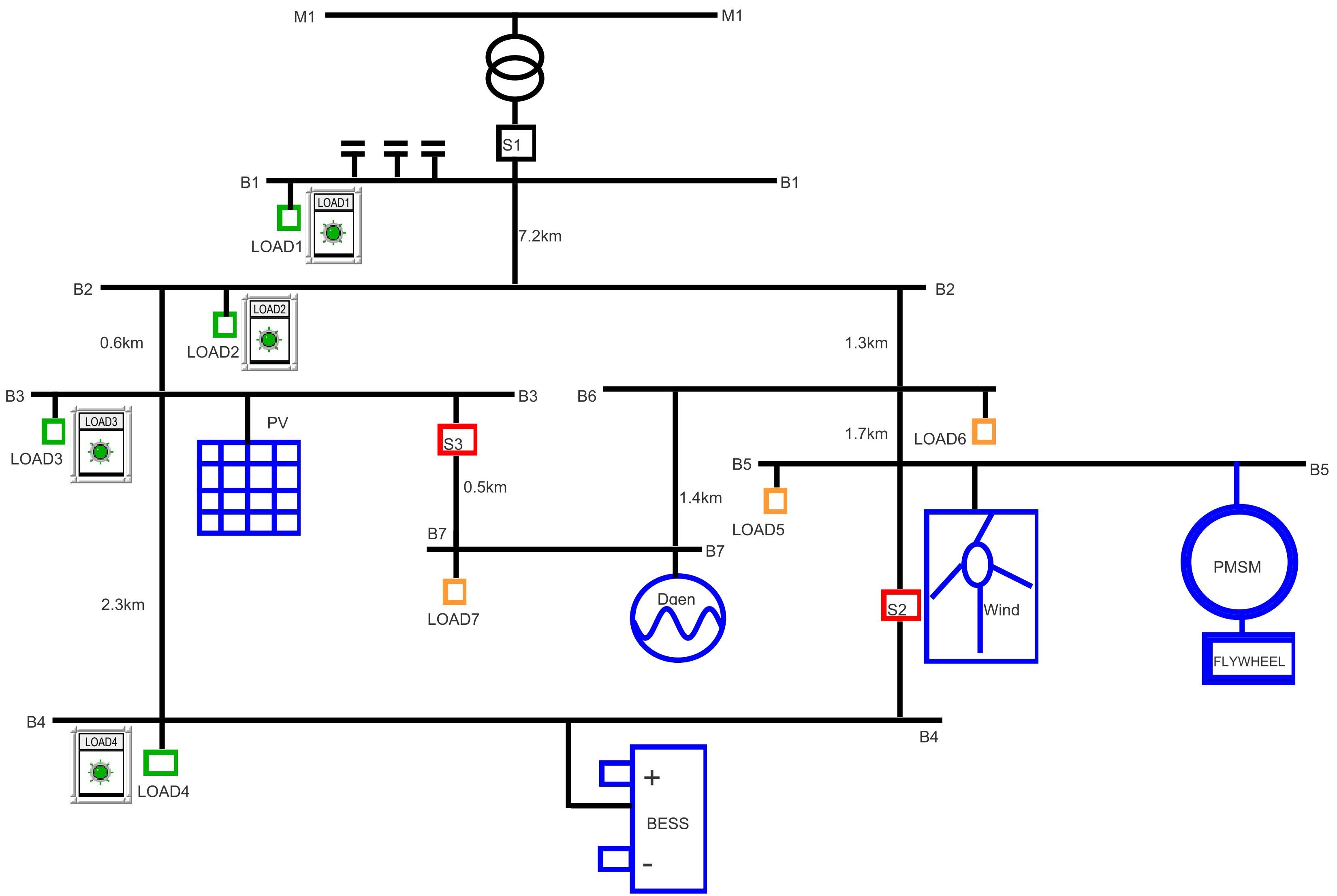
Case 1: Microgrid System with Flywheel & BESS



Case 2: Variable Speed Pumped Hydro