Large-Scale Solar PV Generation Transmission using and Energy Storage-MMC HVDC Link

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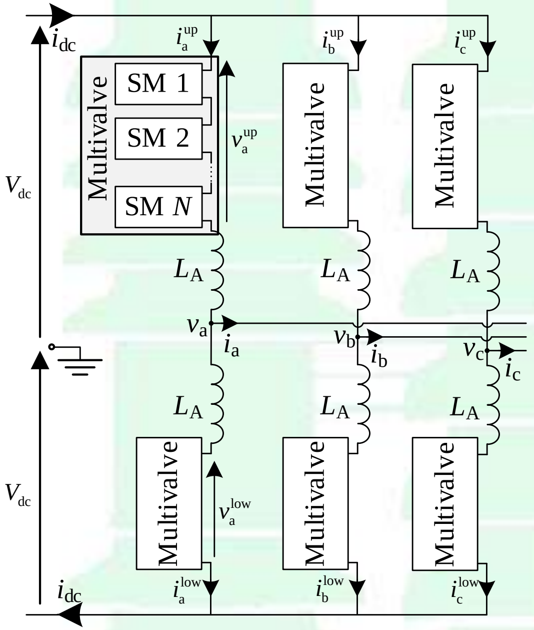
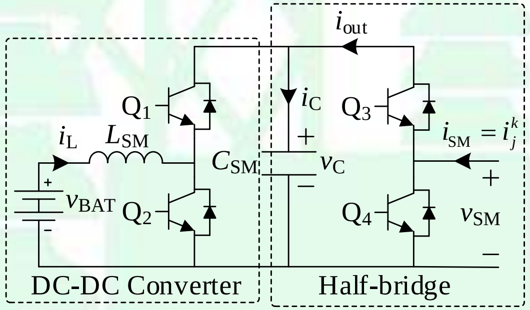
Introduction

- Solar PV power
  - Output depend on irradiance and temperature
  - Located far from load center
  - Grid integration required by inverter
- Long distance power transmission by HVDC
  - Weak systems require VSC HVDC technologies
  - Modular multilevel converter (MMC)
- Handling variable solar PV generation
  - Use batteries to absorb variable power generation
  - Provide frequency support by energy storage
  - Modular multilevel converter with energy storage (MMC-ES)

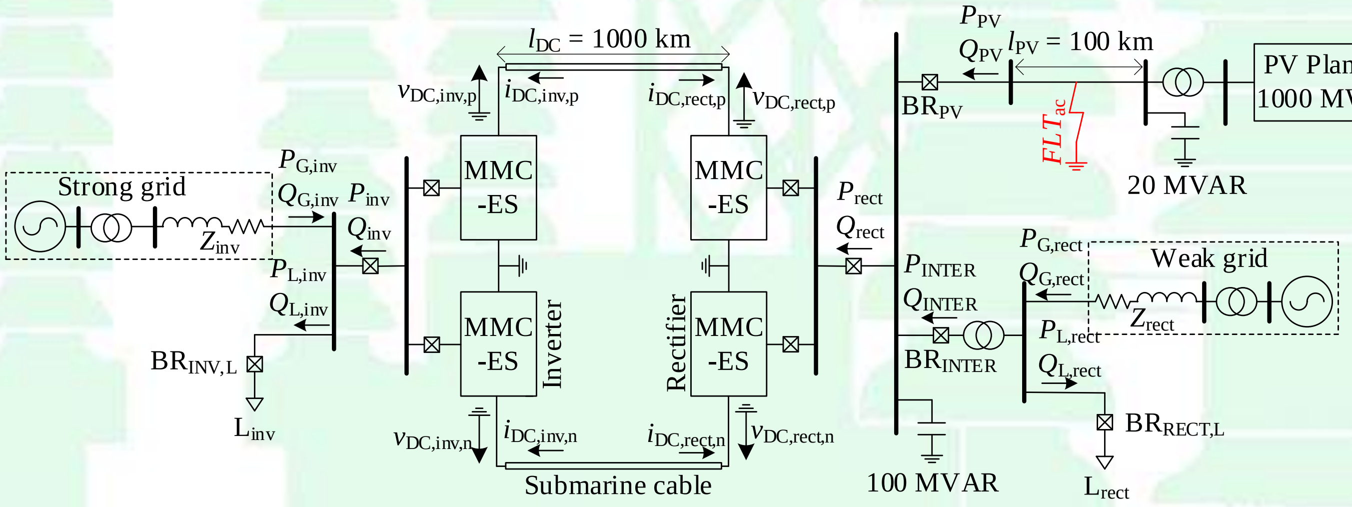
Schematic Diagram of MMC-ES and Study System



(a)
Schematic diagram



(b)
SM topology



Study System

System Parameters

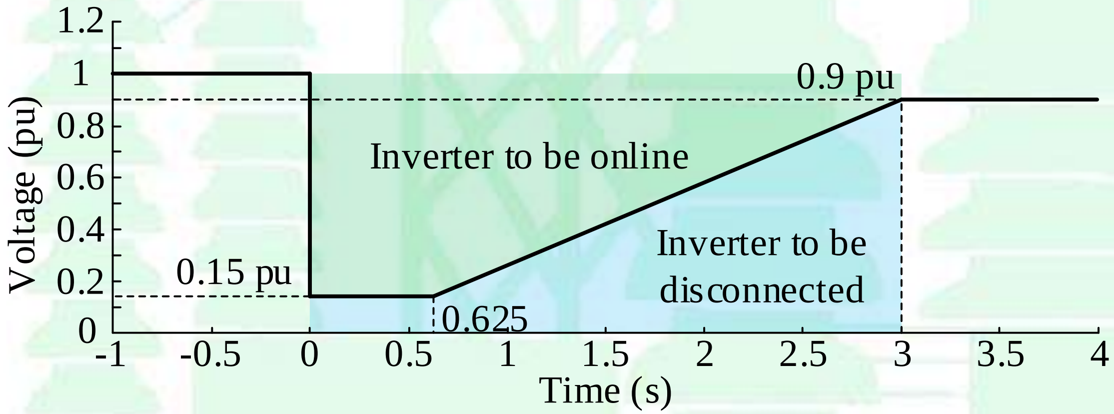
MMC-ES Parameters			
Power rating per pole	500 MW	Number of SMs per arm	300
SM capacitance	8.062 mF	DC voltage	±525 kV
Battery voltage	1 kV	Arm inductance	64.4 mH
Converter ac voltage	300 $kV_{ll,rms}$		
PV Plant Parameters			
PV module	KU330-8BCA	Single inverter power rating	5 MW
Inverter dc link voltage	1.2 kV	Inverter ac voltage	690 V
Total rated PV power	1000 MW	Transmission line length	100 km
Rectifier AC System Parameters			
Inertia	3.5 s	Governor droop	5%
Short circuit ratio	4 @ 75°	Rated frequency	60 Hz
Inverter AC System Parameters			
Inertia	4 s	Governor droop	5%
Short circuit ratio	8.21 @ 76.3°	Rated frequency	60 Hz
DC Cable Parameters			
Length	1000 km	Depth below sea floor	1.5 m
Cable horizontal displacement	0.2 m	Insulation	XLPE

Control Objectives

Control parameter	Rectifier	Inverter
Decoupled q axis current reference	Control ac power	Control dc pole voltage
Decoupled d axis current reference	Control reactive power and support ac voltage	Control reactive power and support ac voltage
DC component of circulating current	DC power injected to the inverter	Not controlled
SM dc-dc converters	Control the average SM capacitor voltage with a feedforward term to inject SM power reference	Control dc-dc converter inductor current to obtain desired amount of power from batteries.

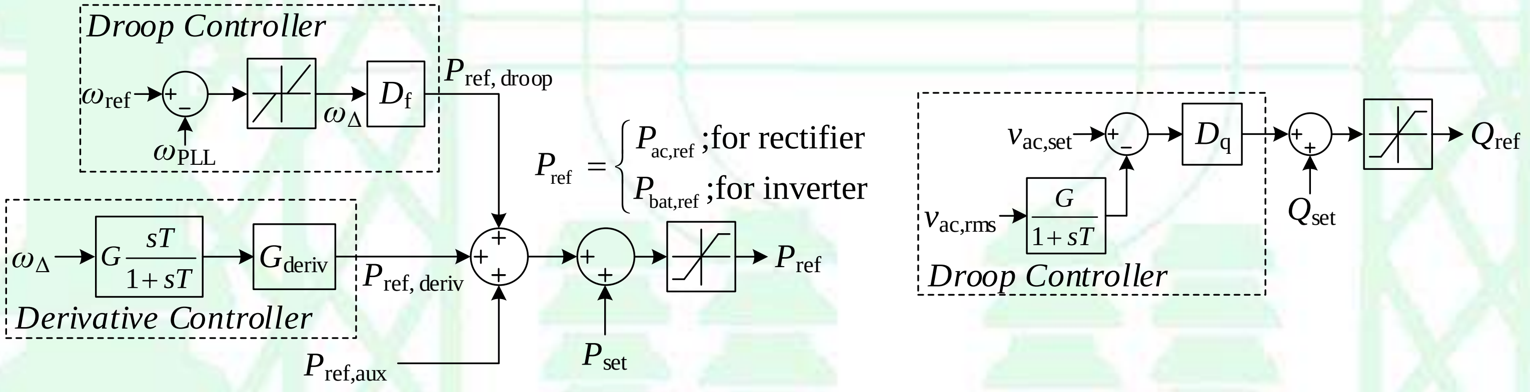
Protection and Fault Ride Through

- DC voltage protection
  - If dc voltage is beyond 0.9-1.1 pu
  - For more than 5 ms
  - Converter is blocked
- DC current protection
  - DC current magnitude exceeds 2 pu
  - For more than 5 ms
  - Converter is blocked



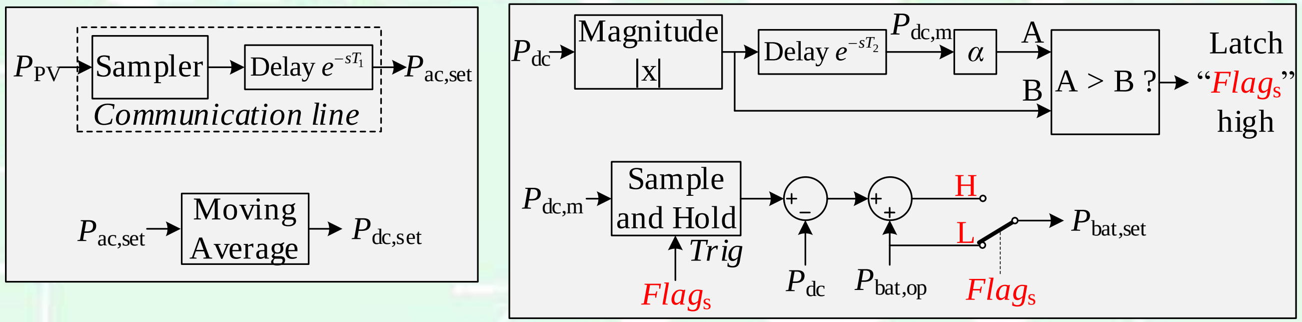
Low ac voltage ride through

MMC-ES Ancillary Services Controllers



(a) (b)

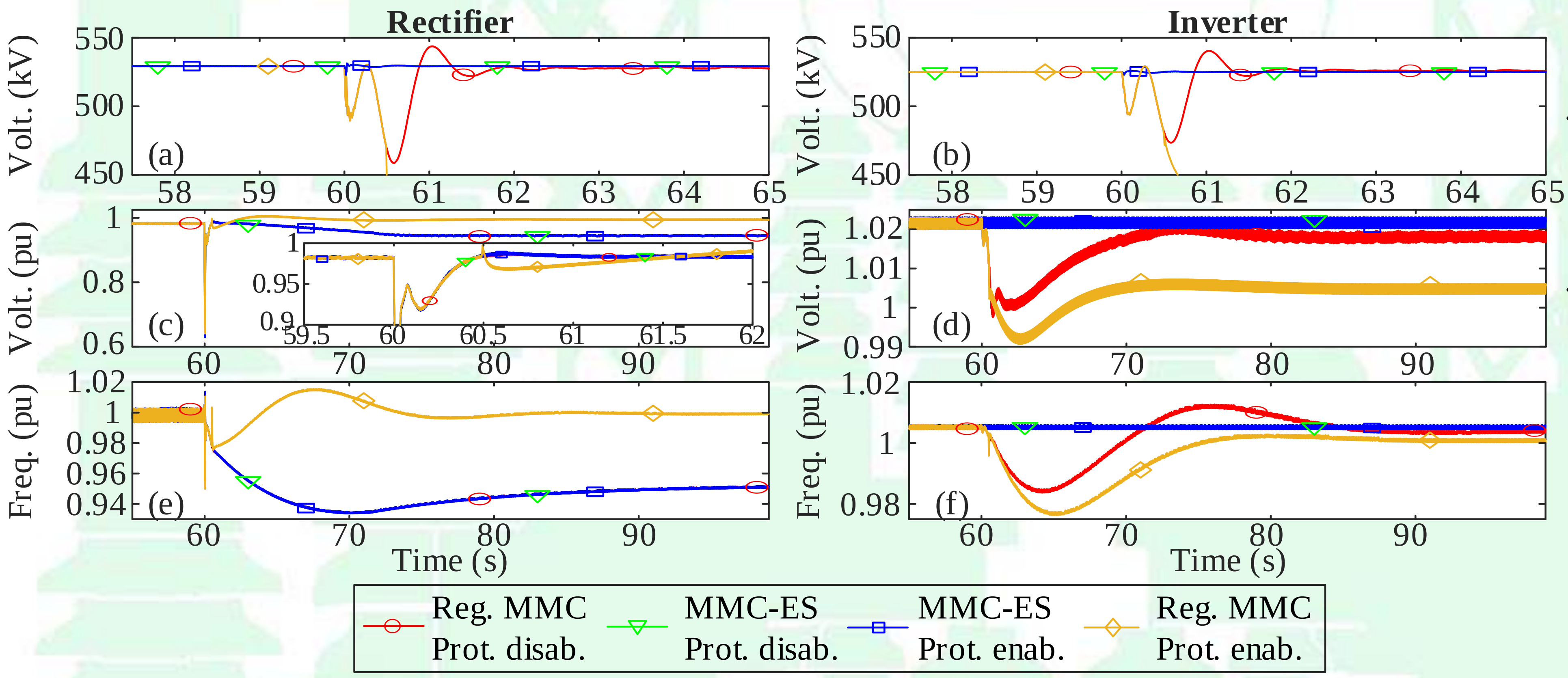
Ancillary control systems (a) active power support (b) reactive power support.



(a) (b)

Power set point calculators with local active power measurements (a) rectifier (b) inverter.

Fault on AC Transmission Line followed by Line Trip: DC Side Response

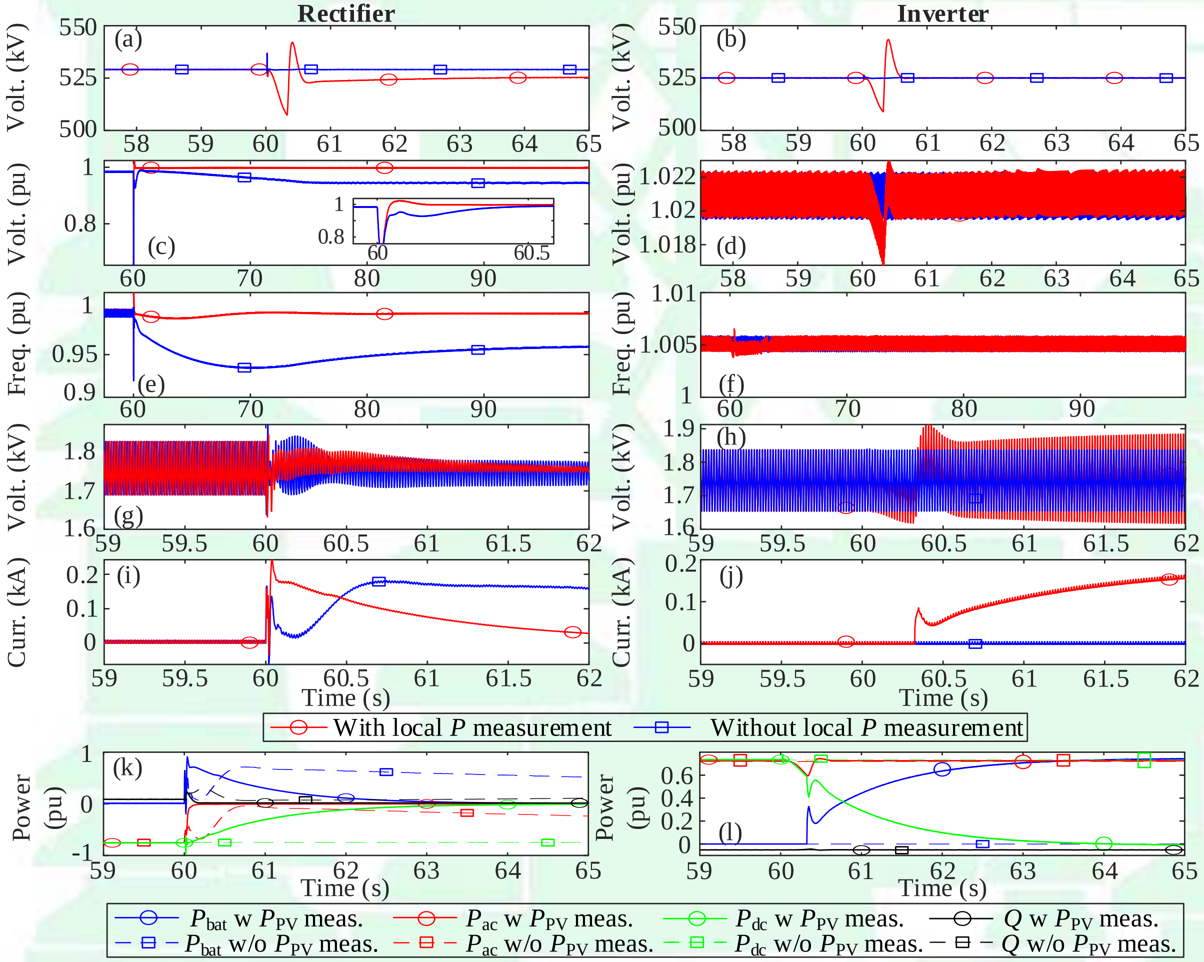


« dc +ve pole voltage

« ac rms voltage at converter

« ac system frequency-from PLL

Impact of Local PV Power Measurement with the Loss of PV Transmission Line Following a Fault



« dc +ve pole voltage

« MMC-ES ac bus voltage

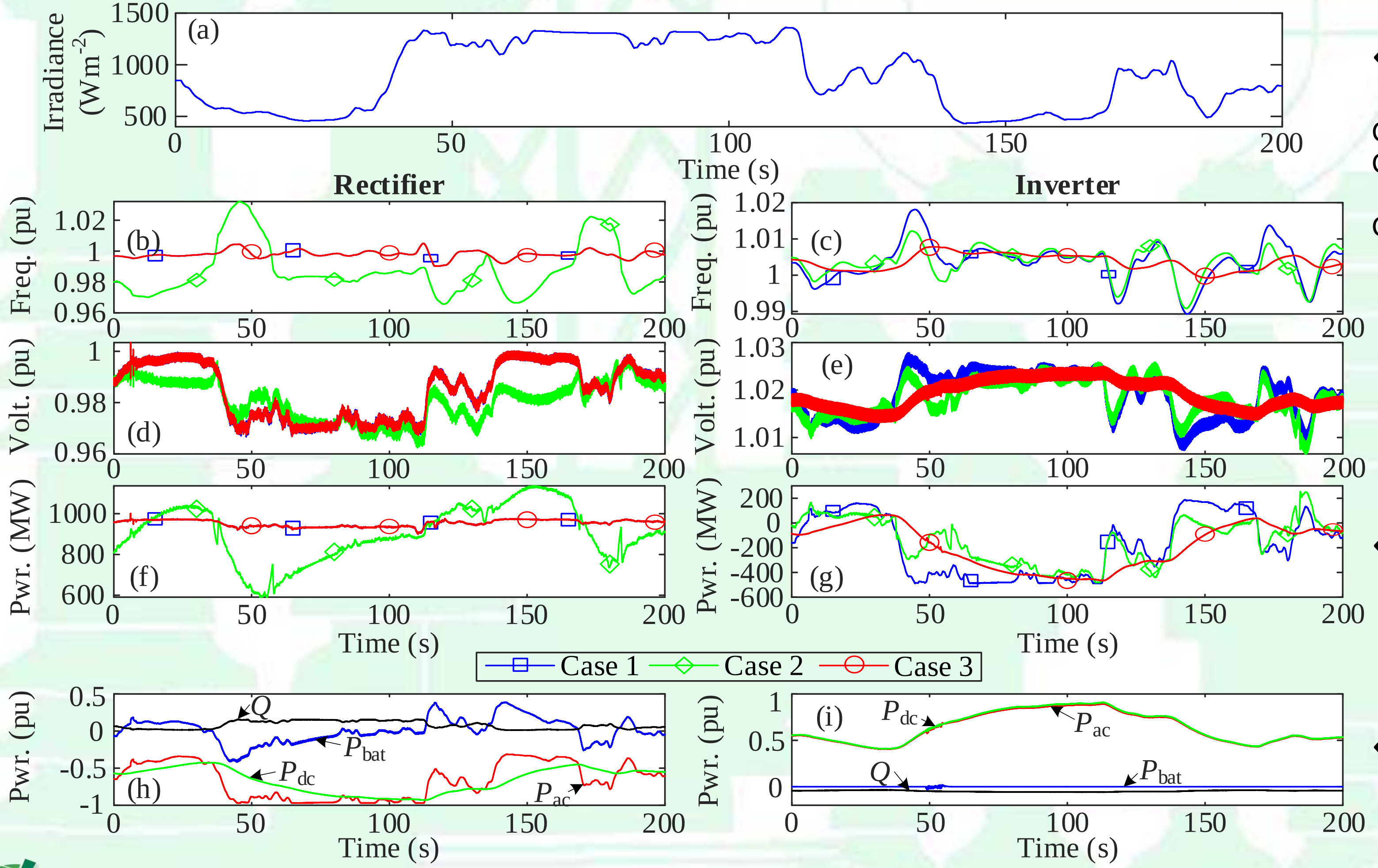
« ac network frequency captured by PLL

« average SM capacitor voltage

« average battery current

« MMC-ES power distribution

System Response to an Irradiance Profile



« tested irradiance profile

Case 1: regular MMC with power set point calculator
Case 2: regular MMC ac power set point from moving average of PV power
Case 3: MMC-ES with power set point calculator

« grid synchronous machine speed

« converter ac bus voltage

« power output of equivalent grid

« power distribution in MMC-ES for case 3

Conclusion

- Predictability and dispatchability are important factors.
- Large scale solar PV quite unpredictable and have low dispatchability.
- MMC-ES could be introduced to increase the dispatchability and predictability of solar PV power.
- Case studies with regular MMC vs MMC-ES, ancillary controller performance for MMC-ES with local PV power measurements, and performance under highly variable solar irradiance are tested.
- The simulation results show that the MMC-ES HVDC solutions are capable of providing attractive alterative for solar PV transmission with power system enhancement.

Thank You!