MATLAB EXPO

2024.06.11 | 그랜드 인터컨티넨탈 서울 파르나스

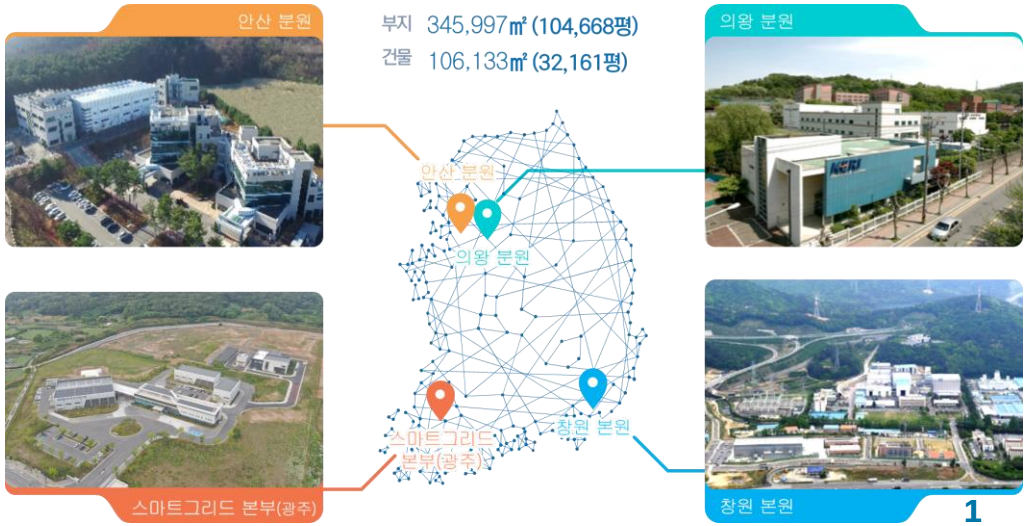
Control and Analysis of Grid-Connected Power Conversion System

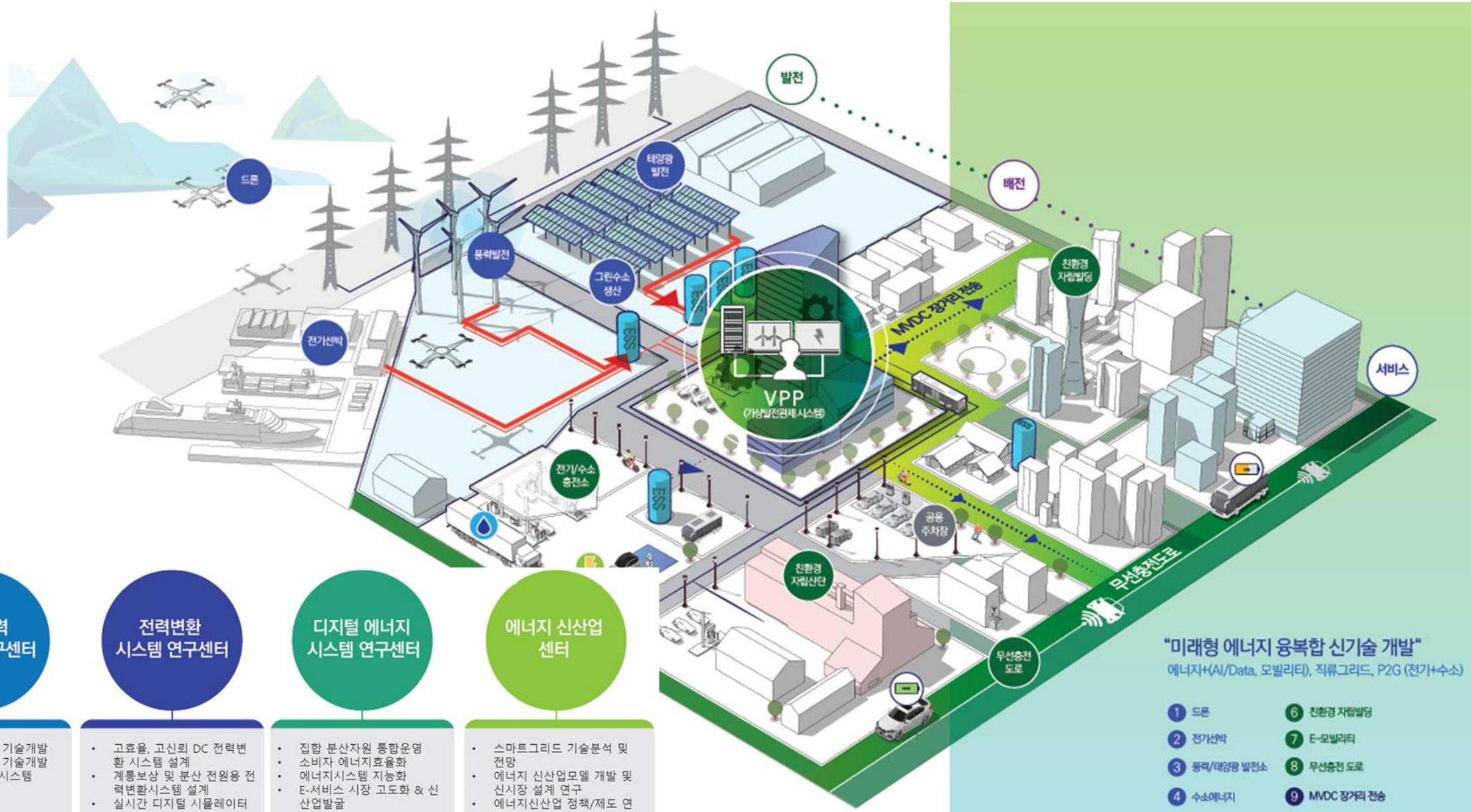
Hyeong-Jun Yoo, Korea Electrotechnology Research Institute

MathWorks

Introduction to Organization and Business

- **KERI 한국전기연구원**
  - 정부출연연구기관 : 국내유일의 전기분야 출연연
  - 주요기능 : 전기분야 연구개발을 통한 국가·산업 발전에 기여
  - 인원 : 671명 (연구직 275명, 기술직 108명, 행정/기타 288명)
- 발표자 : 유형준
  - 선임연구원/Ph.D.
  - 스마트그리드연구본부/분산전력시스템연구센터
  - 연구분야 : 마이크로그리드, 계통연계인버터제어, 전력변환시스템제어, DC 배전시스템, HILS환경에서의 전력시스템 기술 개발





분산전력 시스템 연구센터

- 유연배전시스템 기술개발
- 마이크로그리드 기술개발
- 스마트분산전원시스템 기술개발

전력변환 시스템 연구센터

- 고효율, 고신뢰 DC 전력변환 시스템 설계
- 계통보상 및 분산 전원용 전력변환시스템 설계
- 실시간 디지털 시뮬레이터 기반 전력변환시스템 설계

디지털 에너지 시스템 연구센터

- 집합 분산자원 통합운영
- 소비자 에너지효율화
- 에너지시스템 지능화
- E-서비스 시장 고도화 & 신산업발굴

에너지 신산업 센터

- 스마트그리드 기술분석 및 전망
- 에너지 신산업모델 개발 및 신시장 설계 연구
- 에너지신산업 정책/제도 연구
- 에너지신산업 관련 연구 및 사업기획

Introduction

- 모델링 및 시뮬레이션의 목적 : 경제적, 시간적, 효율적 측면에서 문제점이 발생할 우려가 있는 경우 실제 시스템을 모형화하여 컴퓨터상에 미리 실험하여 사전검토 및 해결방안 도출
  - ex. 가상공간에 실물과 똑같은 물체를 만들어 다양한 모의시험을 통해 검증하는 디지털 트윈은 가상세계에서 장비, 시스템 등의 상태를 모니터링하고 유지/보수 시점을 파악해 개선할 수 있음
- 전력시스템에서의 적용(예시)

Introduction

현재 전력시스템

- 전력시스템 구조
- 접속 전원
- 부하량
- 일사량
- 풍량
- 온도

⋮

시스템 설계

- 접속 전원 용량
- 접속 전원 위치 선정
- 경제성 평가

⋮

전력시스템 해석 & 기술개발 및 성능검증

- 정상상태 운전
  - 조류계산 시뮬레이션
  - 전압 profile
- 과도상태 운전
  - 다이나믹 시뮬레이션
  - 주파수 안정도
  - 전압 안정도
- 제어 및 운영기술 개발
  - 대상시스템 제어 및 운영 기술 개발
  - 개발 기술 성능 검증

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MATLAB & SIMULINK

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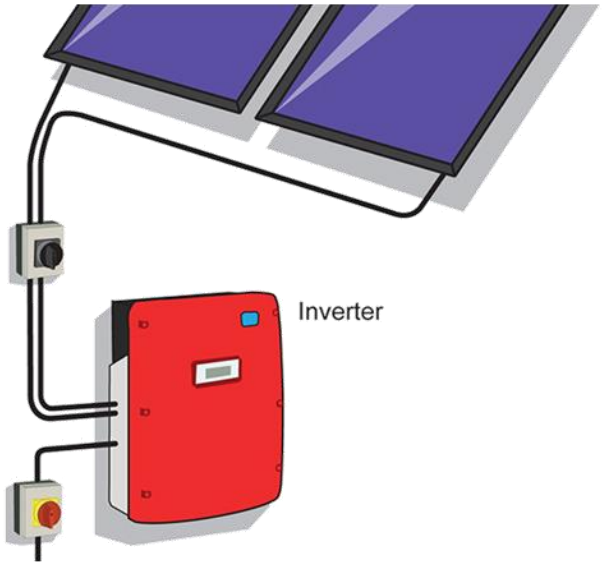
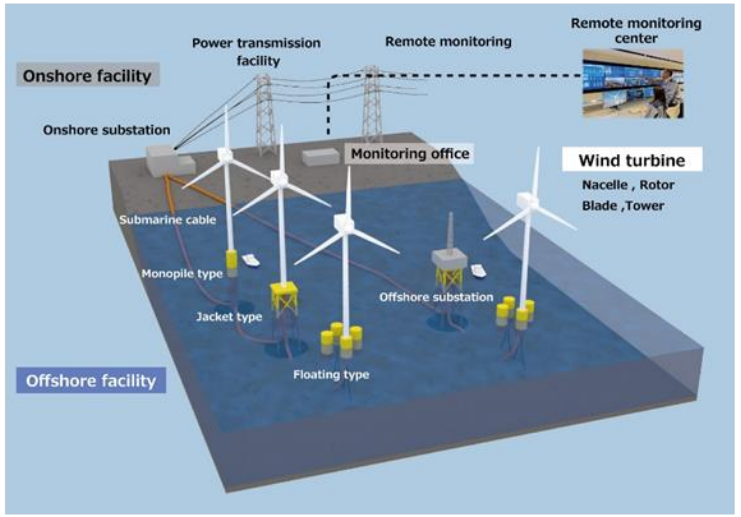
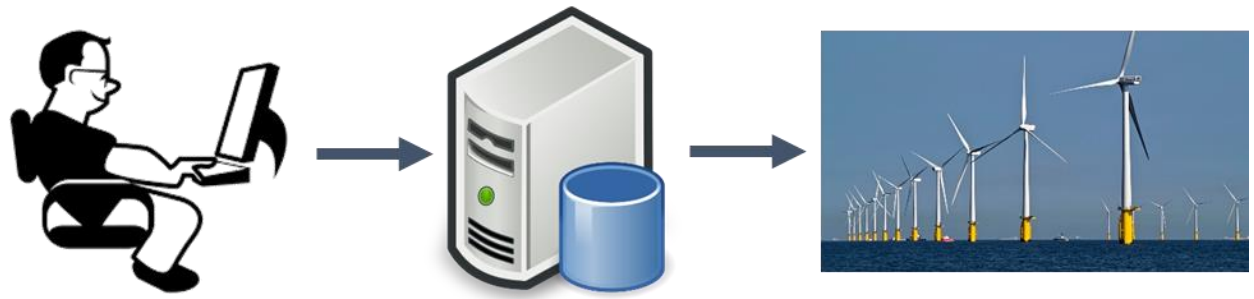
Introduction

- Development of PV Inverter controller



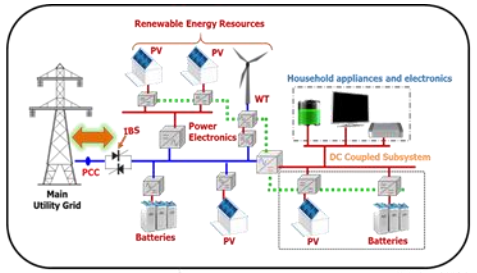
- Development of System operation technology

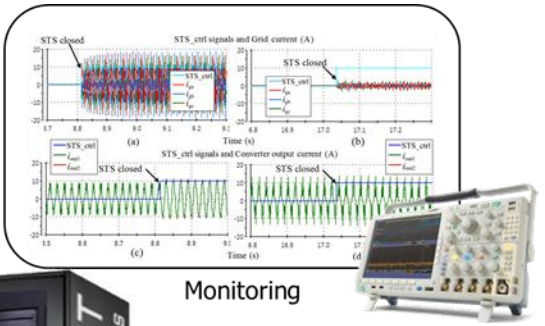




Why HILS?

- 실제 플랜트 모델을 사용 가능한가?
  - 비용 문제 → 실시간 시뮬레이션을 이용한 플랜트 모델 구현(단일기기, 시스템 등)
- 제어기 검증을 위한 실제 플랜트 모델 사용 시, 안전성 확보가 가능한가?
  - 안전성 확보 문제 → 실시간 시뮬레이션 사용으로 테스트 환경의 안정성 확보
- 실제 플랜트 모델에서 다양한 시나리오를 통한 제어기 검증이 가능한가?
  - 안전성 및 개발 시간 문제 → 안전한 테스트 환경 제공 및 개발 시간 단축 가능





Modeling

Monitoring

Real-Time Digital Simulator

Analog signal from RTDS to controller

Analog & Digital signal from controller to RTDS

Control Design Process

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RSCAD® Fx

by RTDS Technologies

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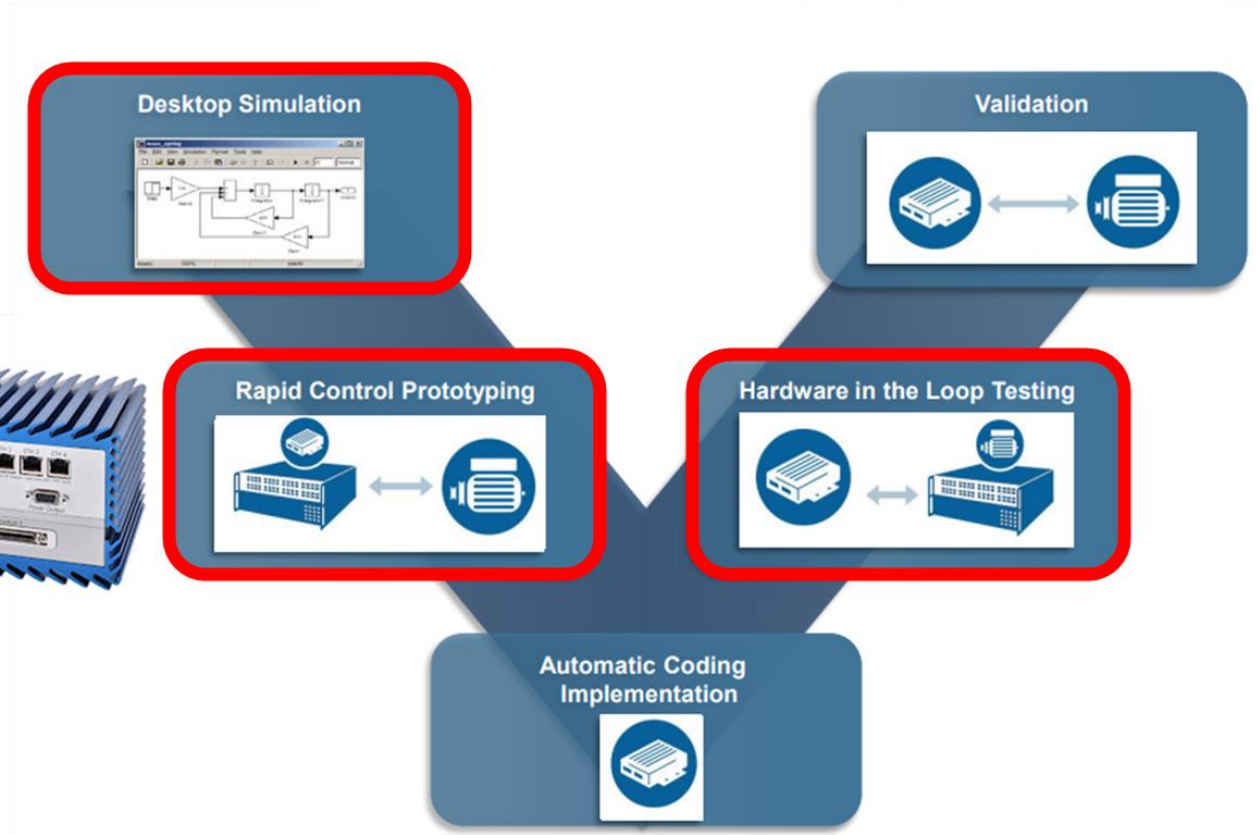
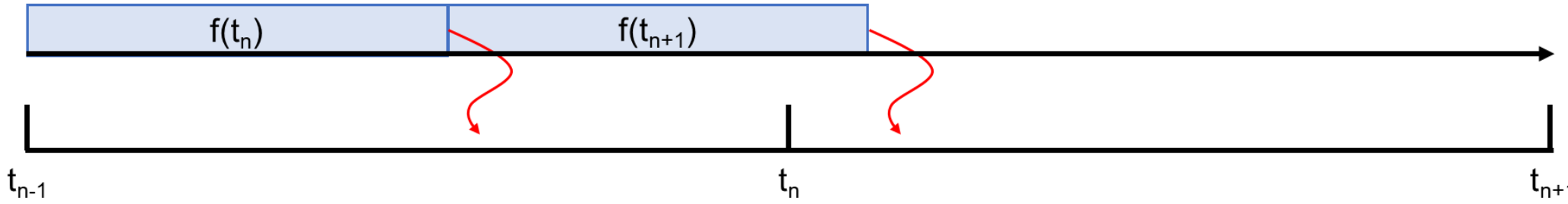
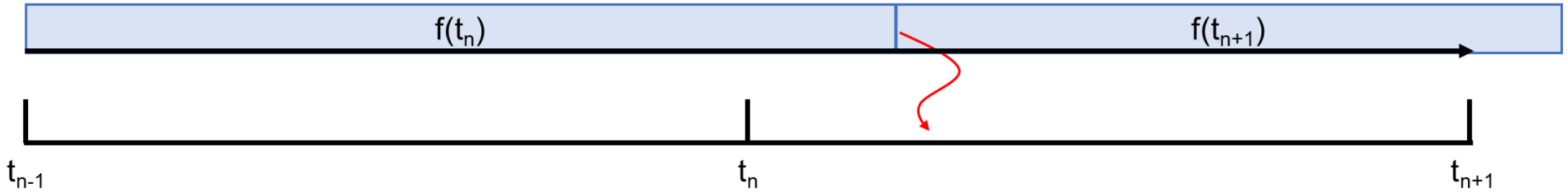


Real-Time Simulation

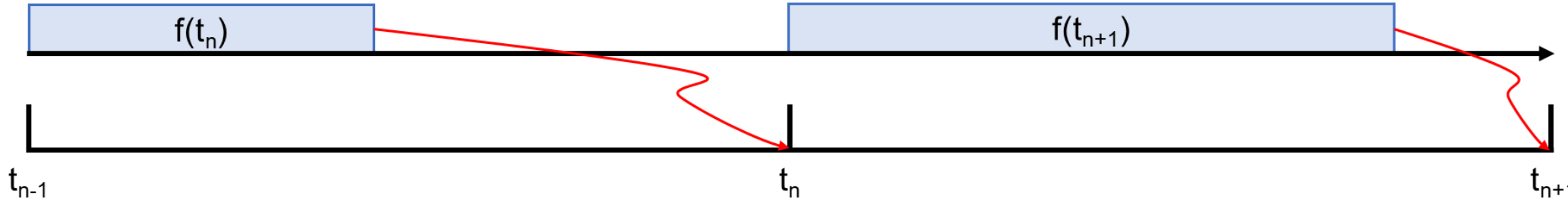
- Faster than real-time (Off-line simulation)



- Slower than real-time(Off-line simulation)



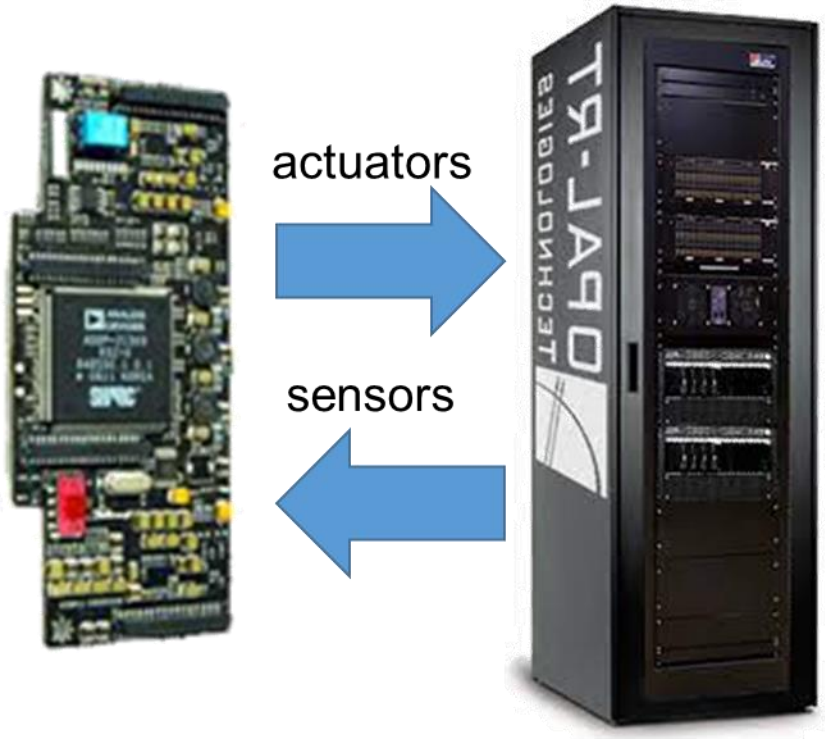
- Real-Time Simulation (On-line simulation)

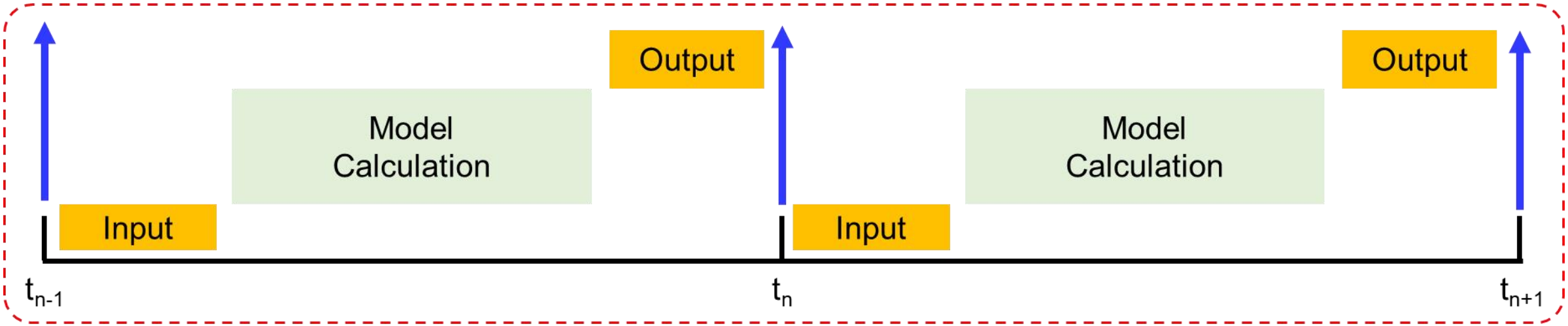


Real-Time Simulation with H/W

- Real-Time & H/W(Embedded system)
  - To read input signal(sensors)
  - To perform all necessary calculations(control algorithm)
  - To write all outputs(control the actuators, PWM, turn on/off)

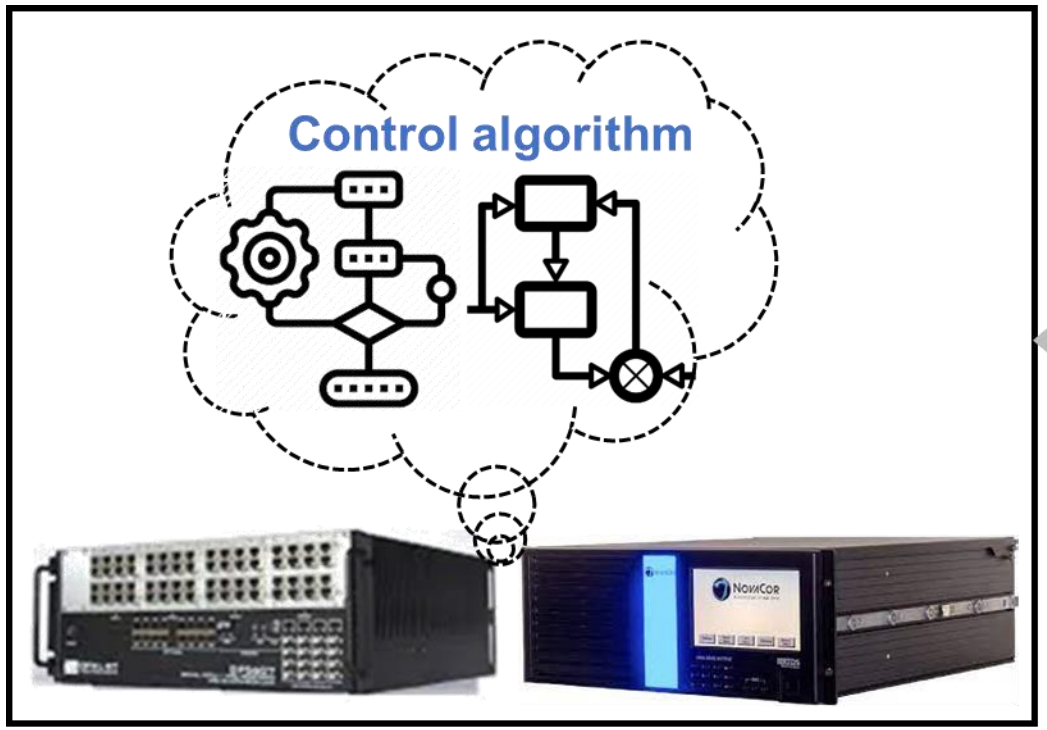
If overrun occur, one step sample is skipped and calculations are performed in the next time-step





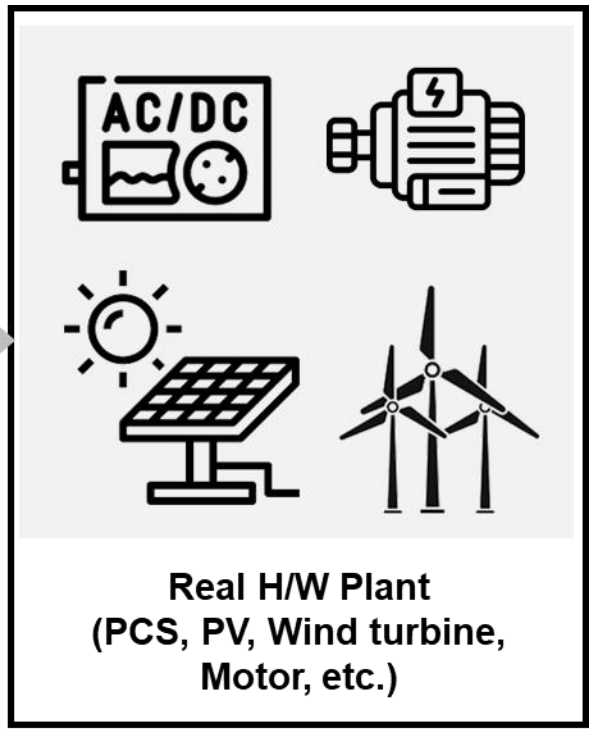
Rapid Controller Prototyping(RCP)

- Definition is a type of simulation methodology that allows for the rapid evaluation of control system, especially for large machinery.
  - It is a very efficient method to develop, optimize, and test new control strategies in RT environment quickly without manual programming.



Real-Time Simulator

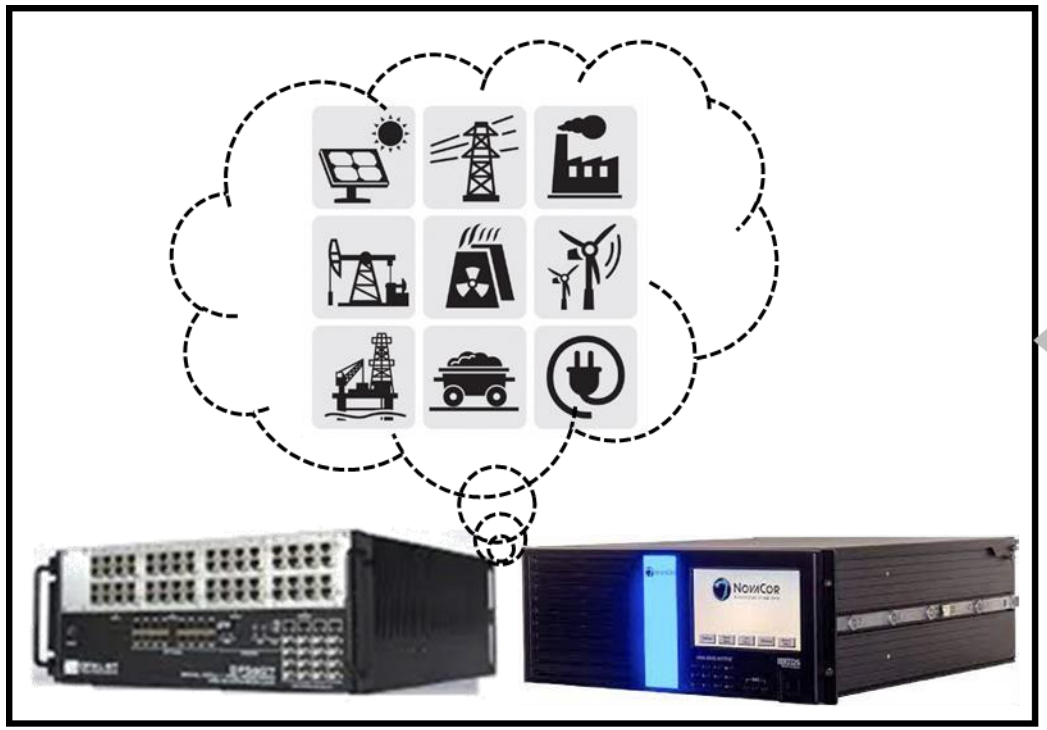
- Low-Power Signal conditioning (±1 to 10V, few mA)
- Optical fibers and communication systems



Hardware under test

Hardware-in-the-loop (HIL)

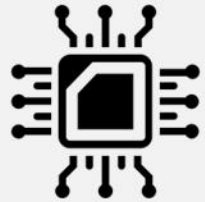
- HIL or CHIL(controller in-the-loop) simulation is real-time plant model(grid, motor, etc.) interfaced to a piece of hardware under test usually with low-power signal interfaces



Real-Time Simulator

- Low-Power Signal conditioning (±1 to 10V, few mA)
- Optical fibers and communication systems

Relay



Controller(HVDC, PV, ESS, Motor, etc.)

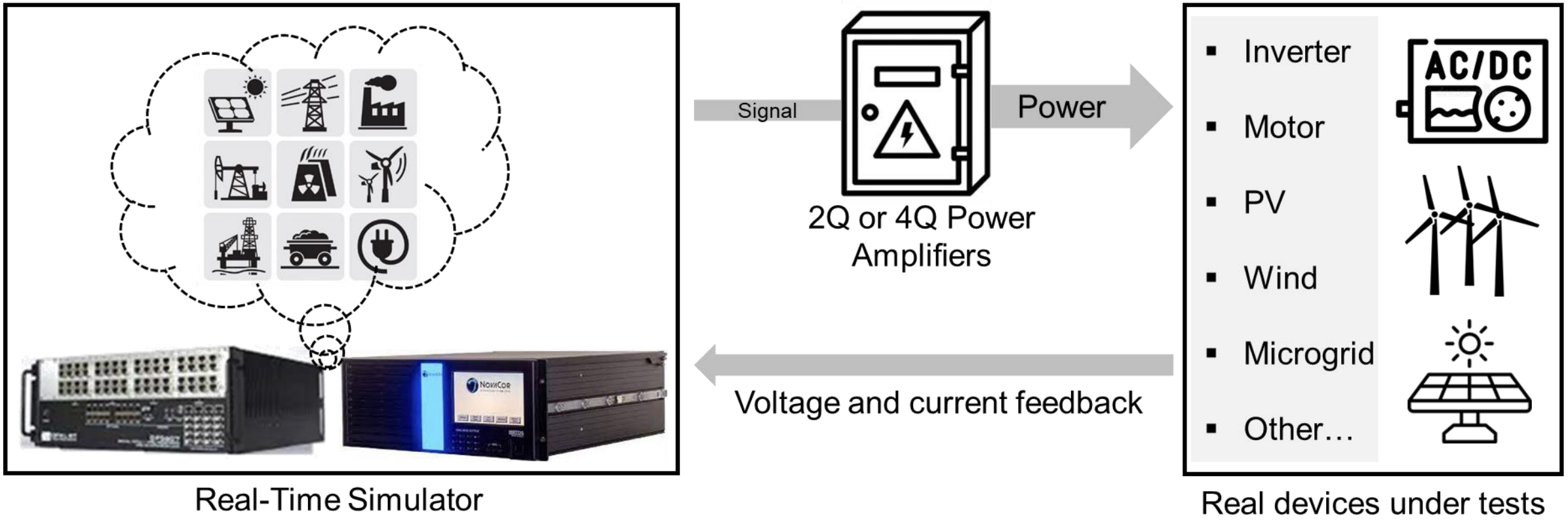
SCADA (SPS)

Real controller, protection devices and communication systems

Hardware under test

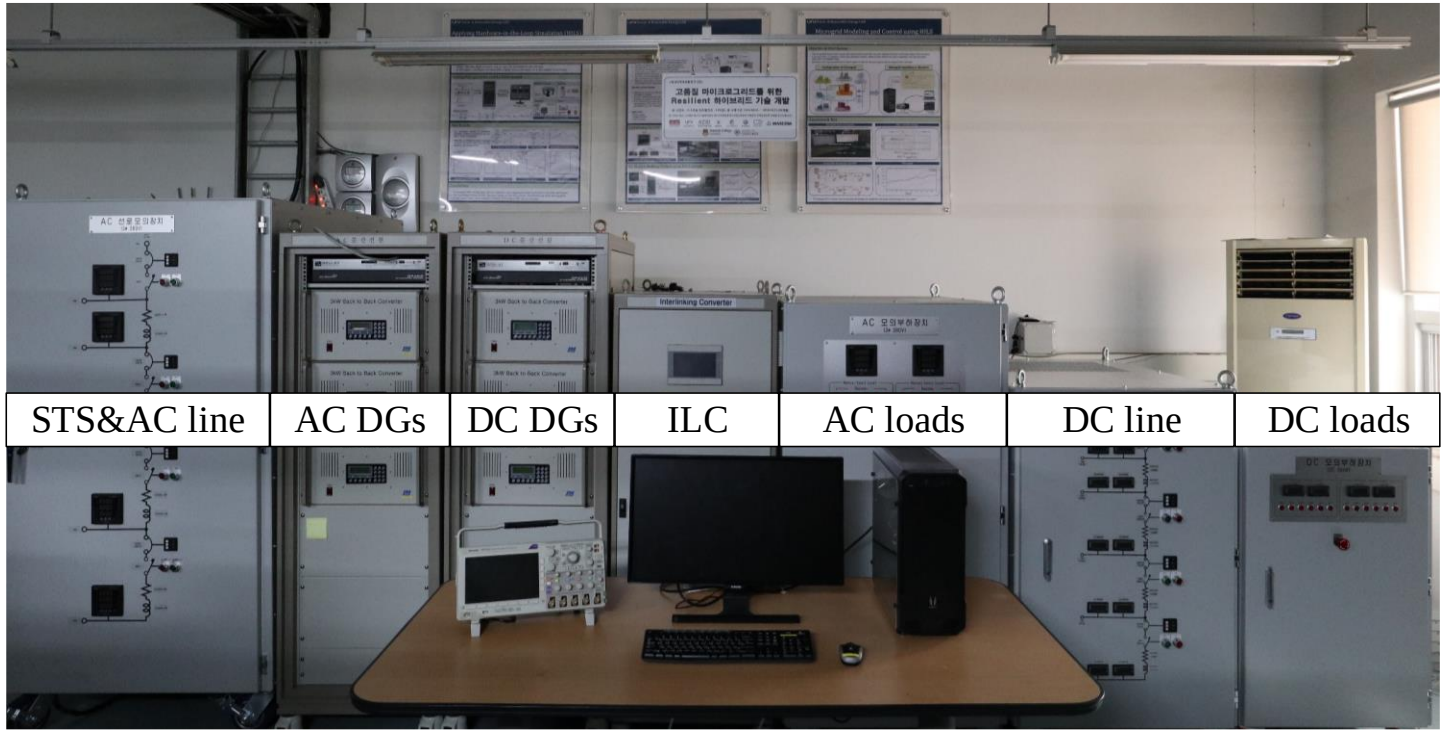
Power Hardware-in-the-loop(PHIL)

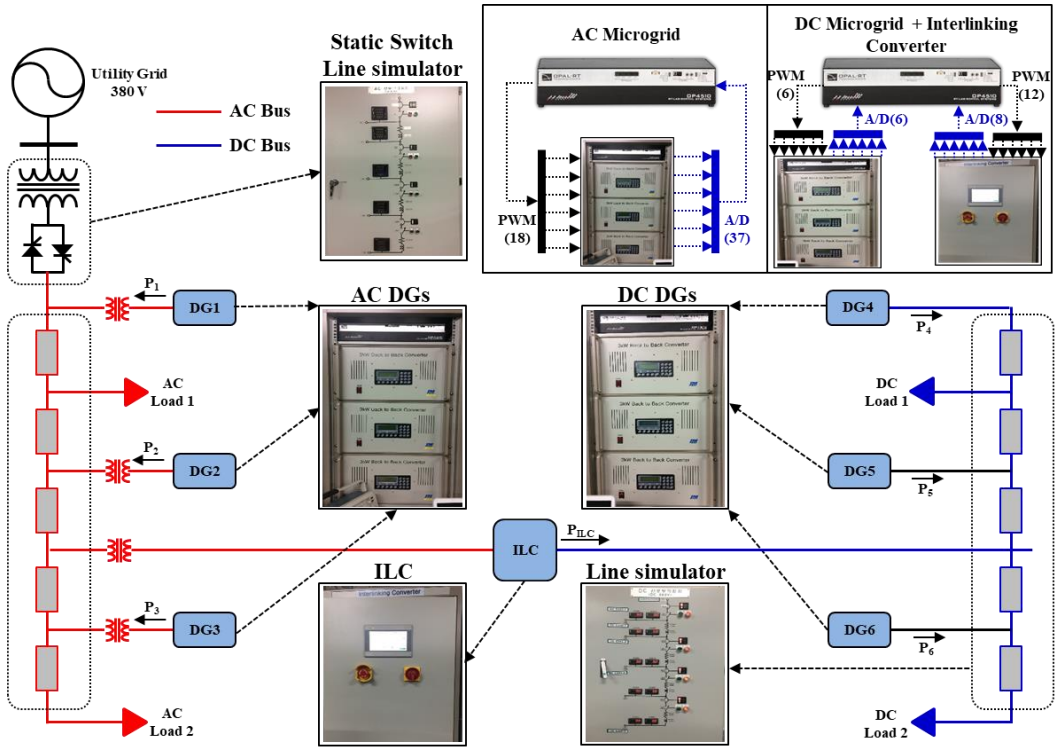
- PHIL simulation is the integrated simulation of a complete system with one part simulated numerically and the other part using real devices



RCP App. – AC/DC Hybrid Microgrids

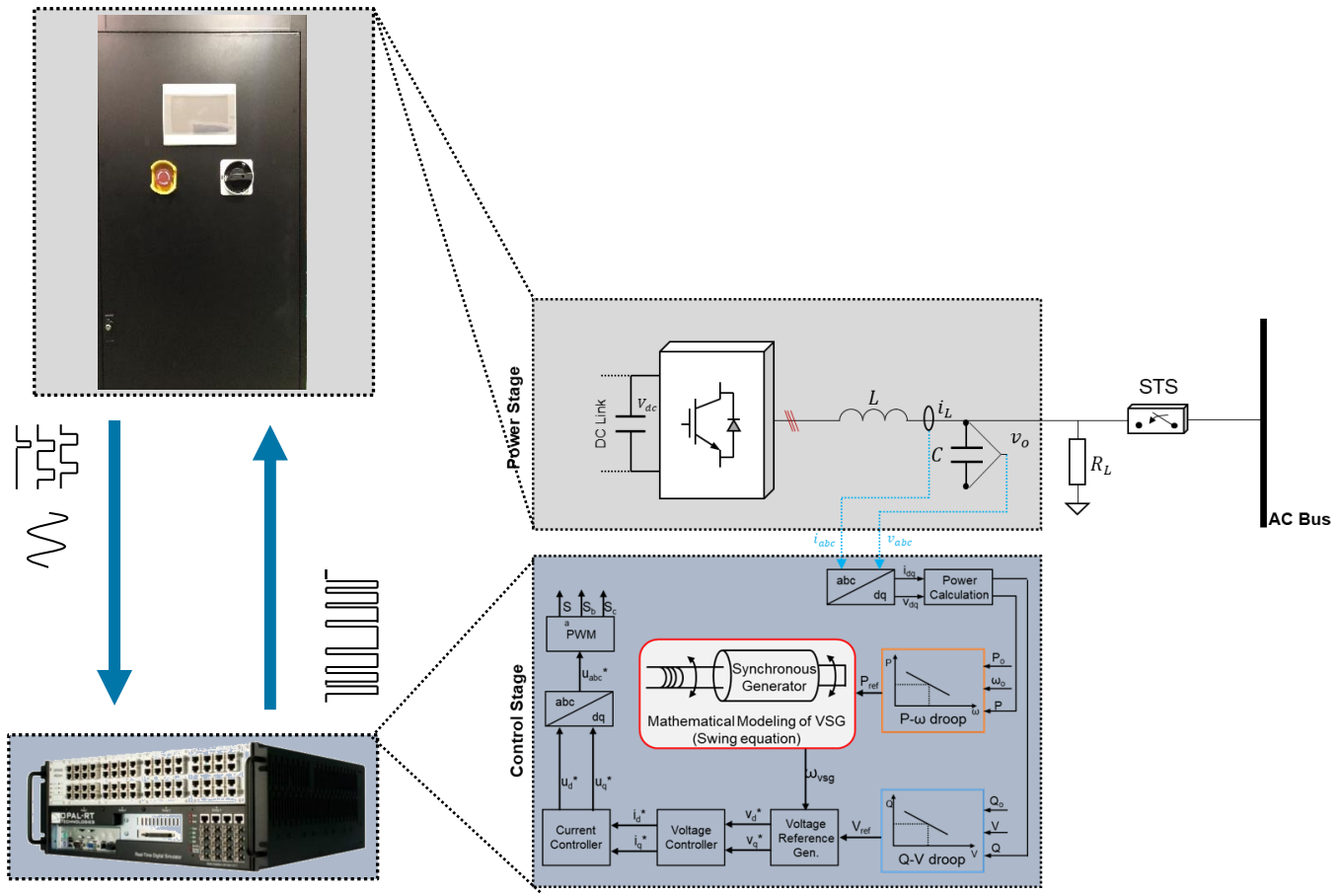
- Two OP4510 control the IBRs(H/W) in AC&DC microgrids
- Interlinking converter control the power flow between AC & DC microgrids

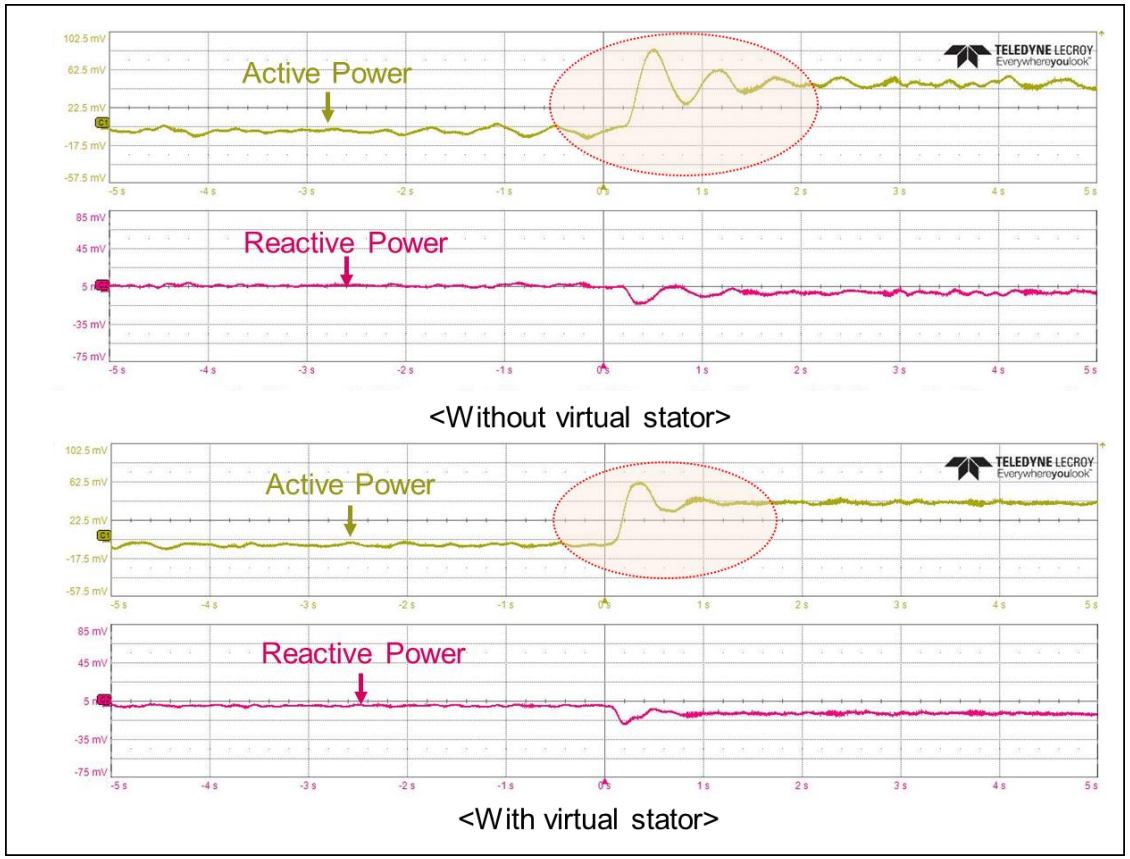




RCP App. – GFM-based Virtual Inertia

- GFM-based virtual inertia algorithm was implemented in OP5600
- The virtual stator algorithm was added to compensate for oscillation

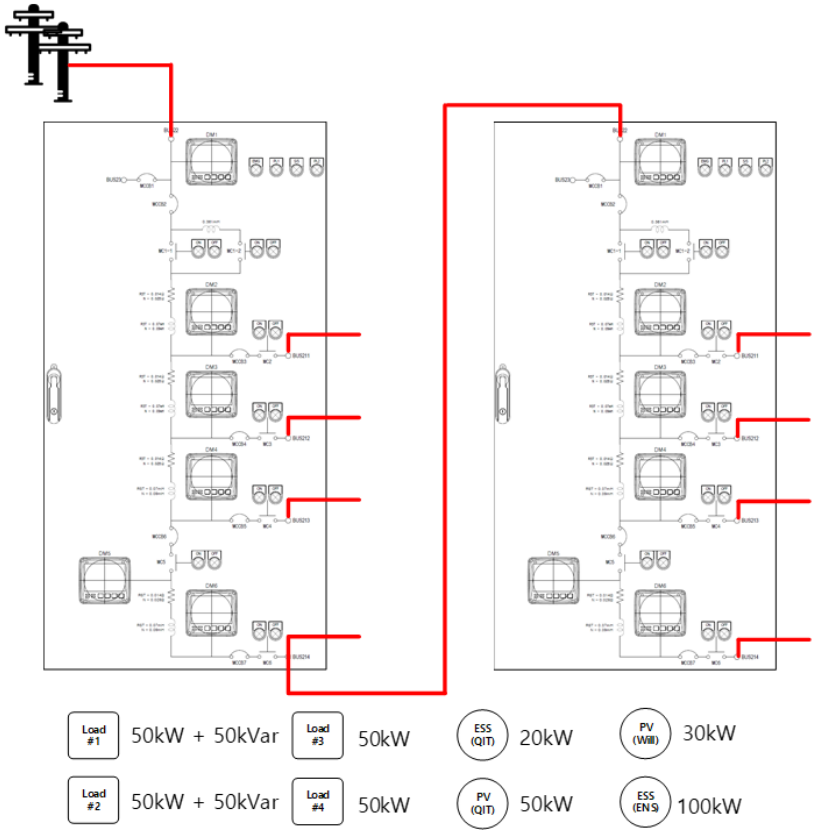


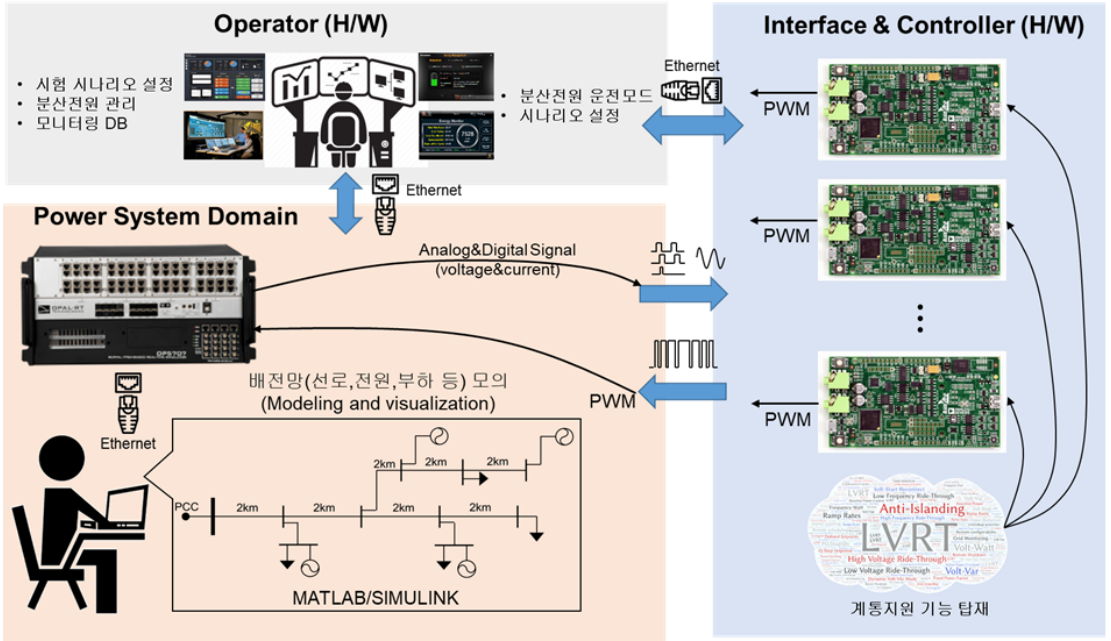


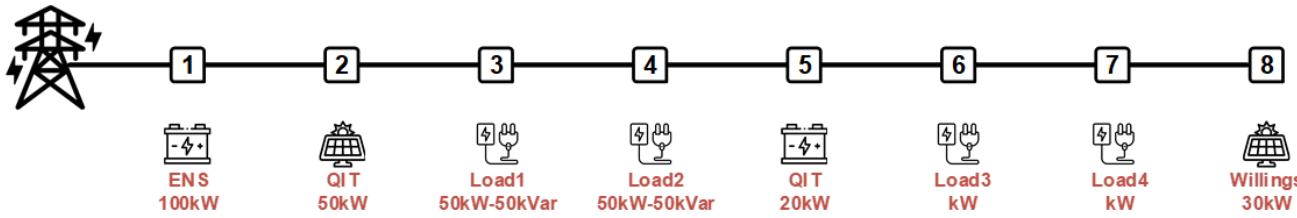
<Experimental results>

HILS App. – Smart Inverter

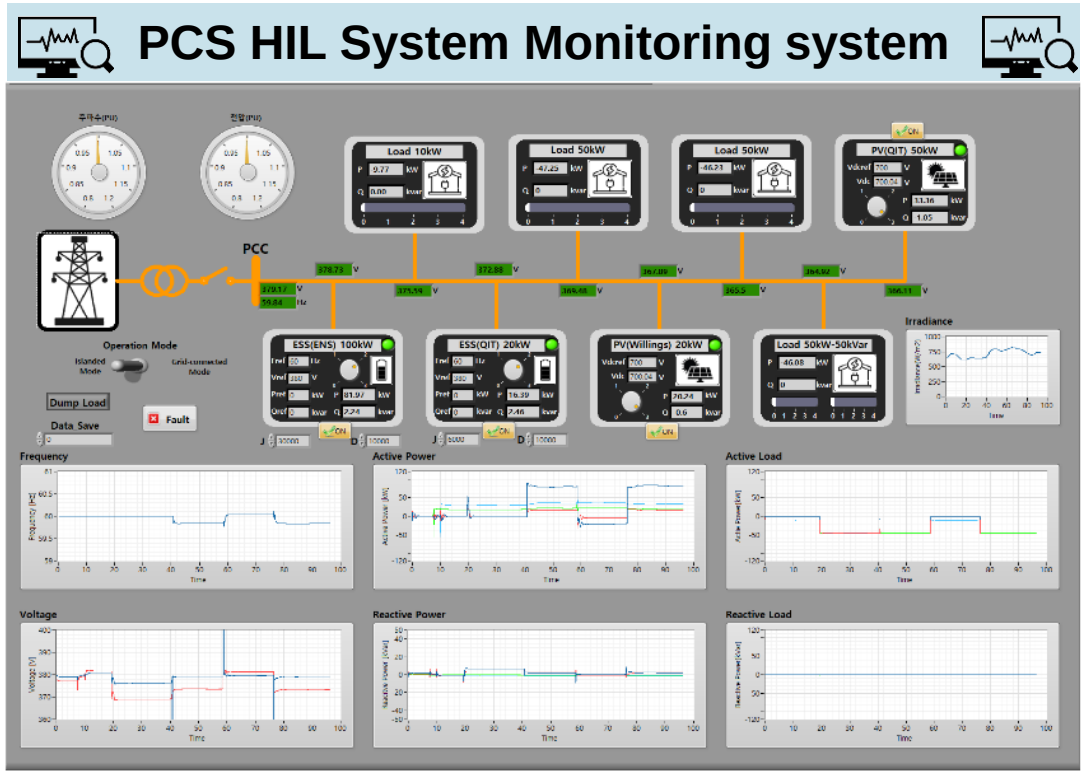
- Development of Smart inverter controller
  - Grid support function(IEEE1547-2018)
  - Design of the distributed power system to verify smart inverter effectiveness
  - Construction of Test-Bed and HIL verification

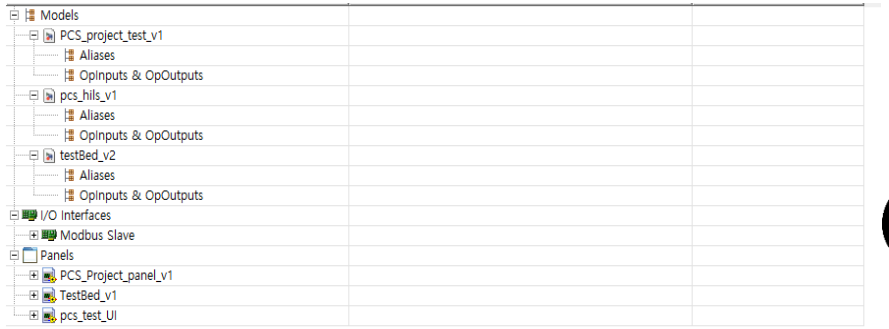


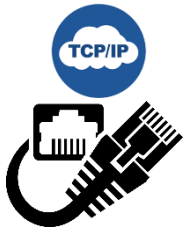


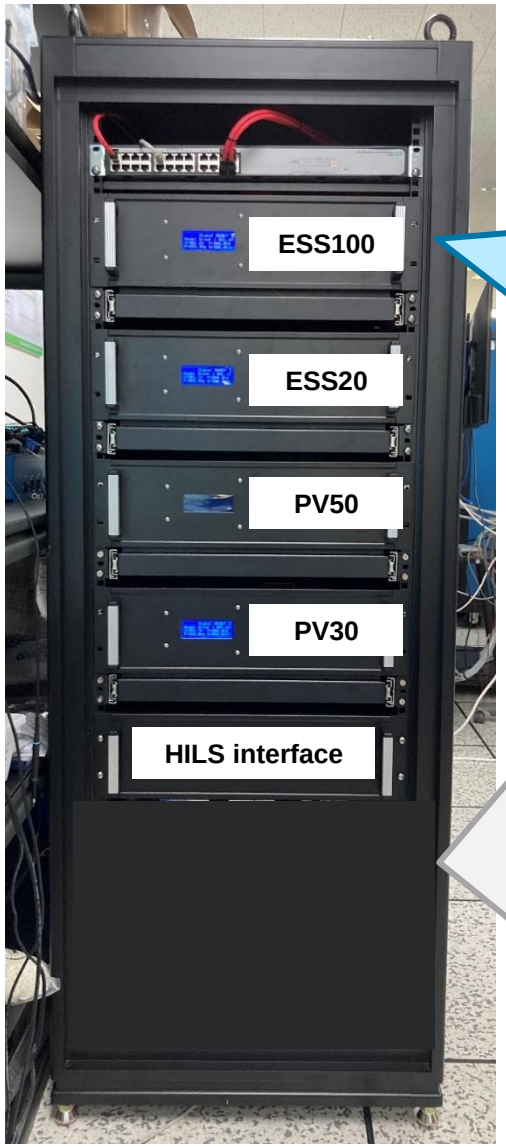


HILS App. – Smart Inverter

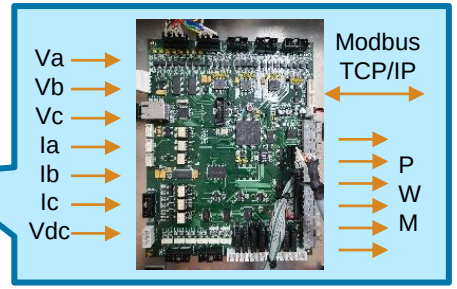


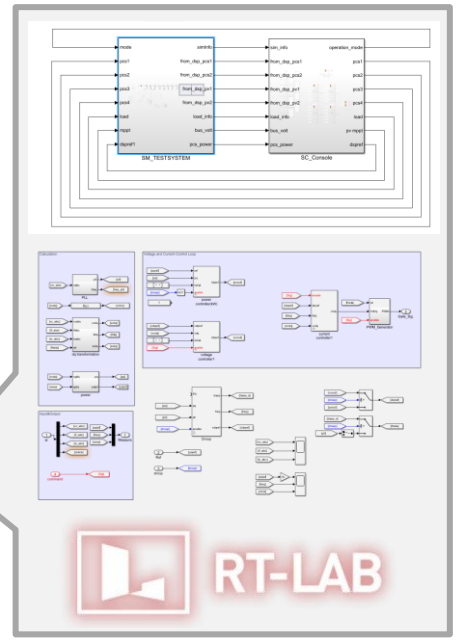






Control board of PCS

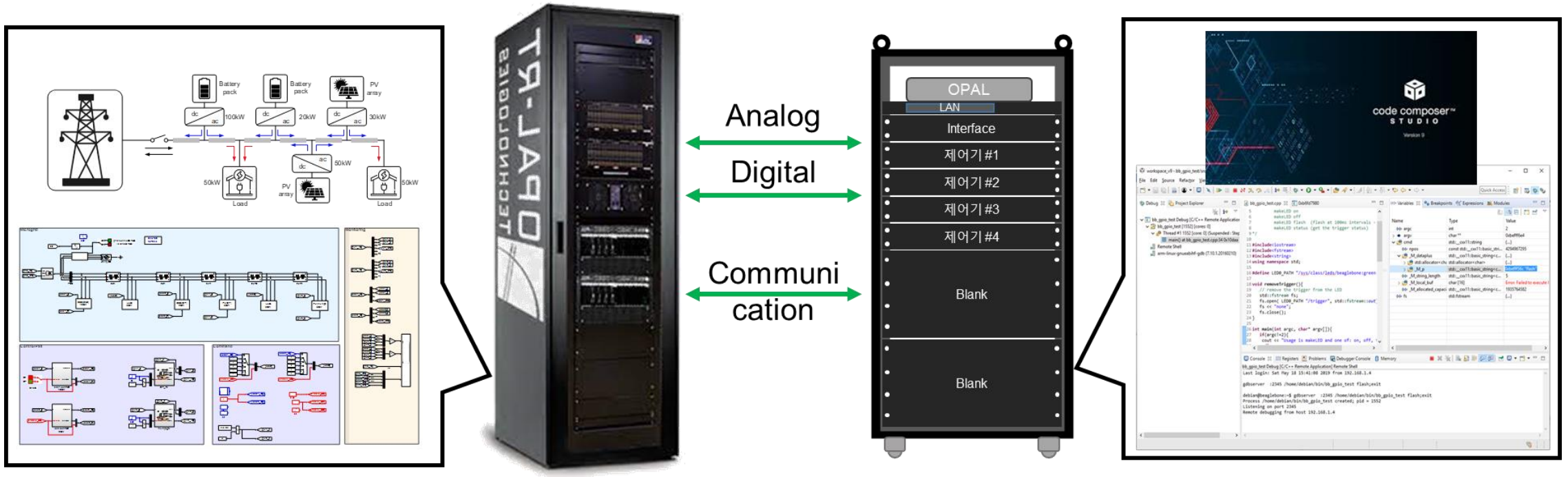




OPAL-RT real-time simulation (Power system analysis)

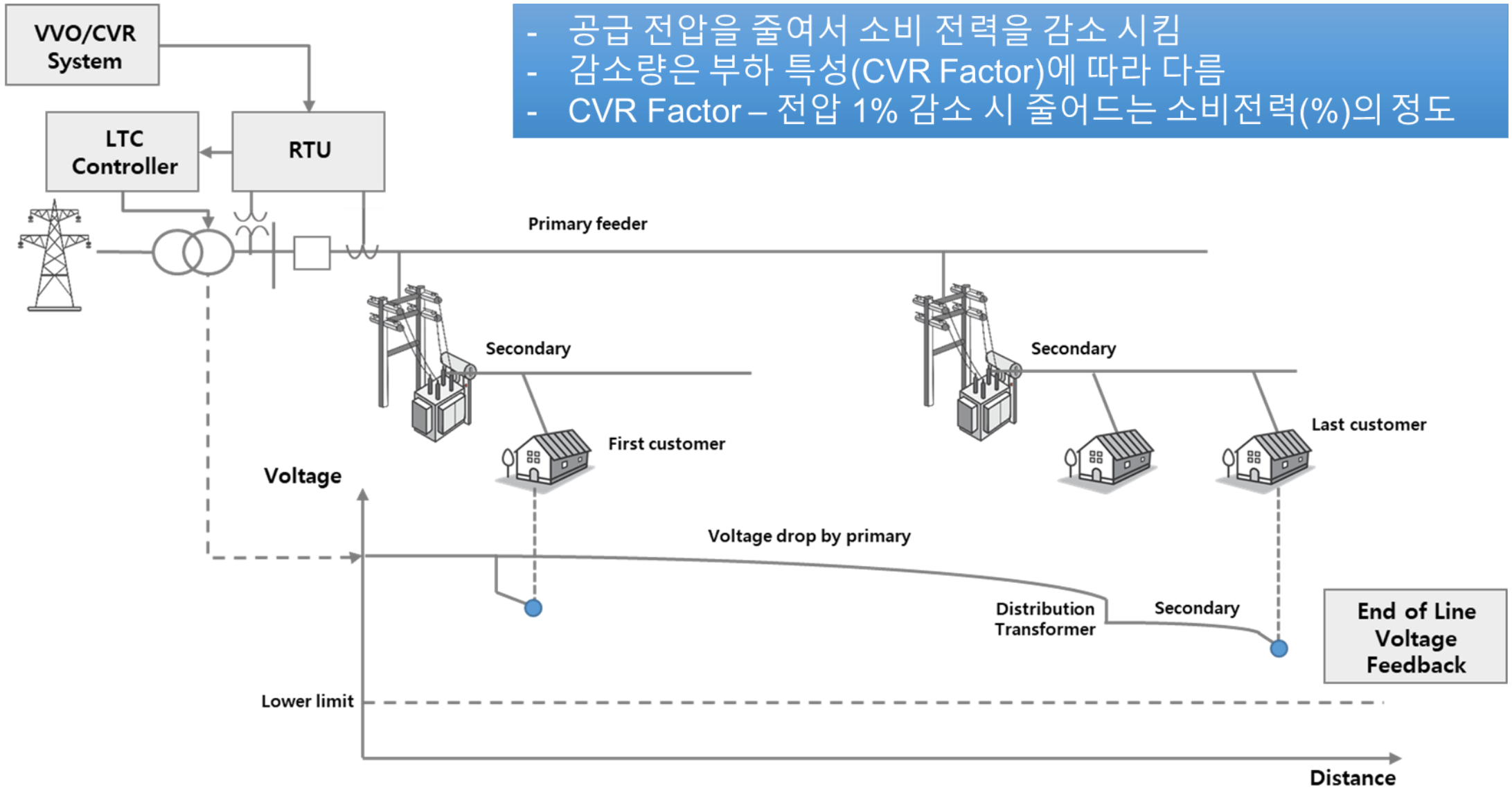
HILS App. – Grid-Forming Inverter

- Development and simulation verification of grid-forming inverter control algorithm (matlab/Simulink)
- Feasibility review of the developed algorithm using RCP
- Performance review of the developed algorithm in the HILS environment (various case studies)

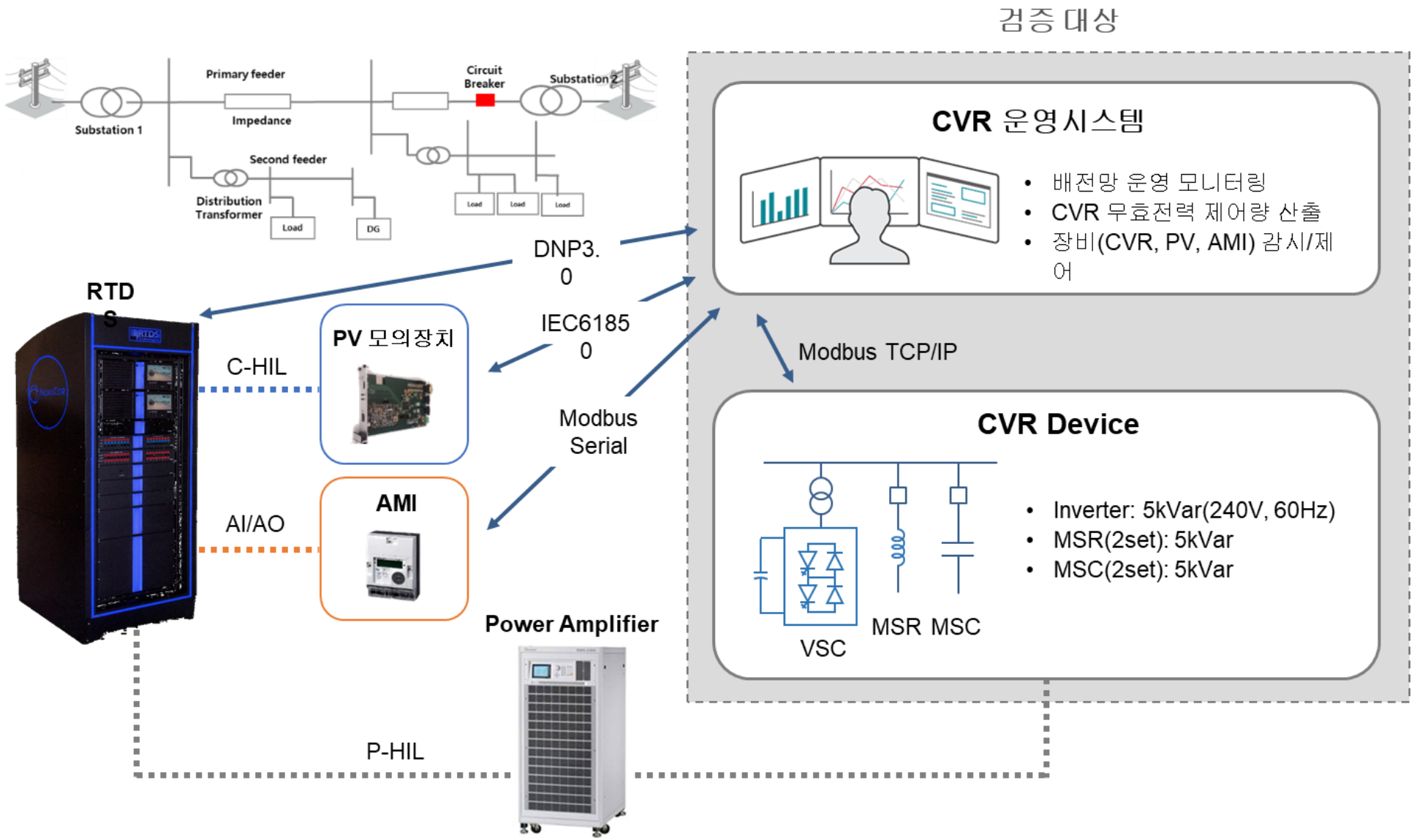


PHIL App. – Development of CVR Technology

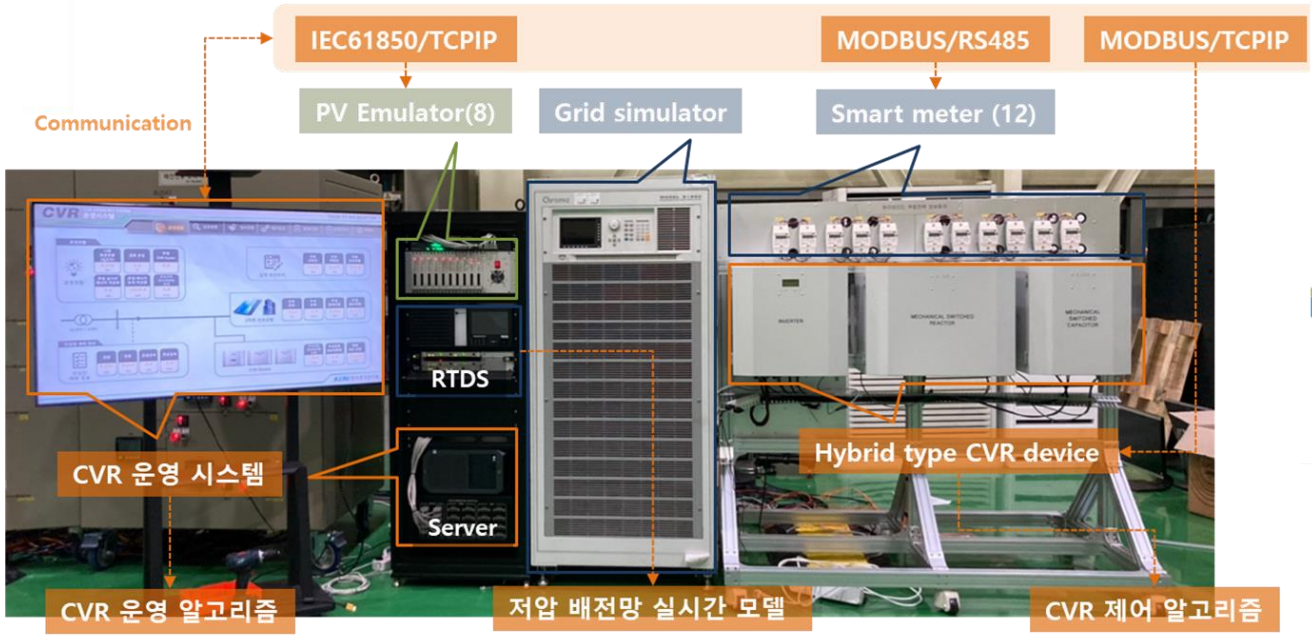
- 공급 전압을 줄여서 소비 전력을 감소 시킴
- 감소량은 부하 특성(CVR Factor)에 따라 다름
- CVR Factor – 전압 1% 감소 시 줄어드는 소비전력(%)의 정도

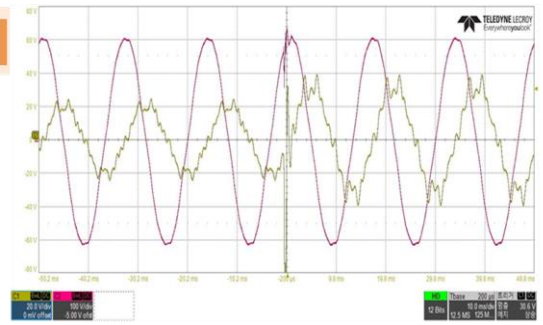


PHIL App. – Development of CVR Technology

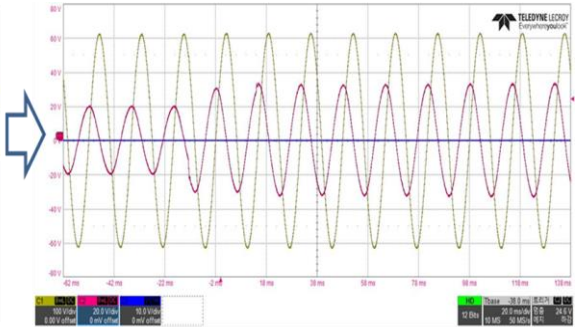


PHIL App. – Development of CVR Technology

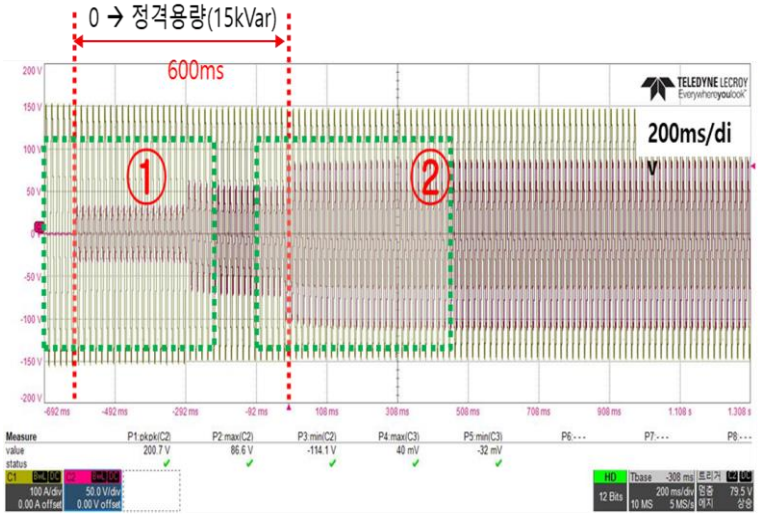


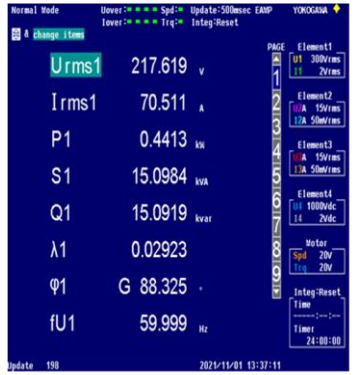


고조파 필터 적용 전 MSC 전류 파형

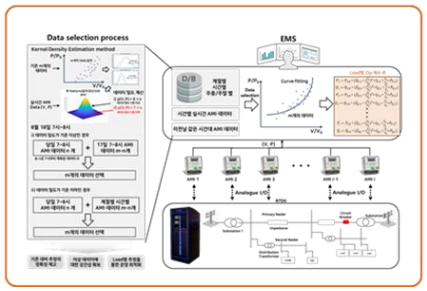


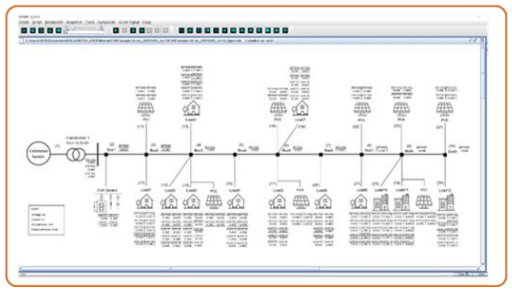
고조파 필터 적용 후 MSC 전류 파형

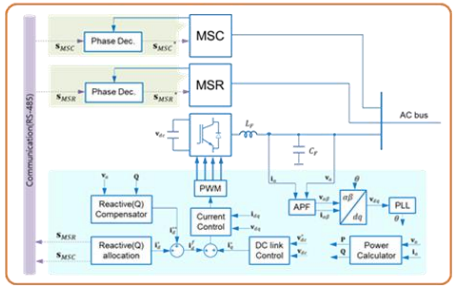




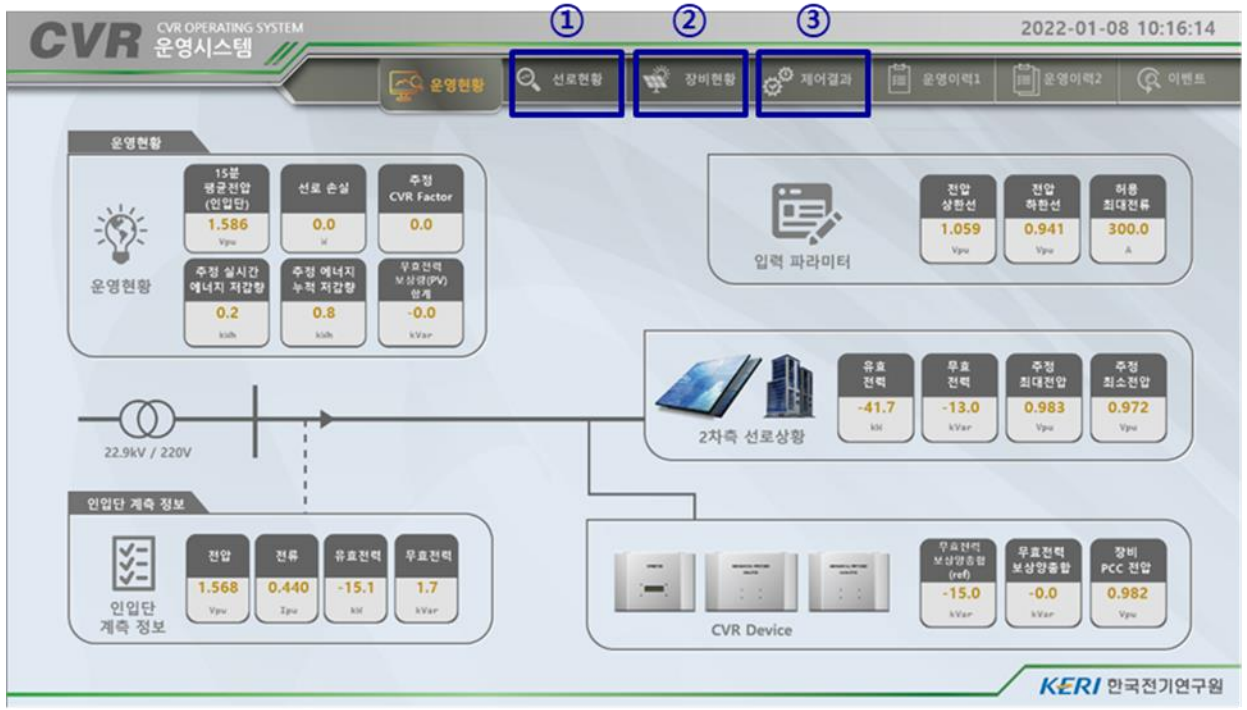
Output 15 kVar, Efficiency: 97%
(Power analyzer, WT3000)

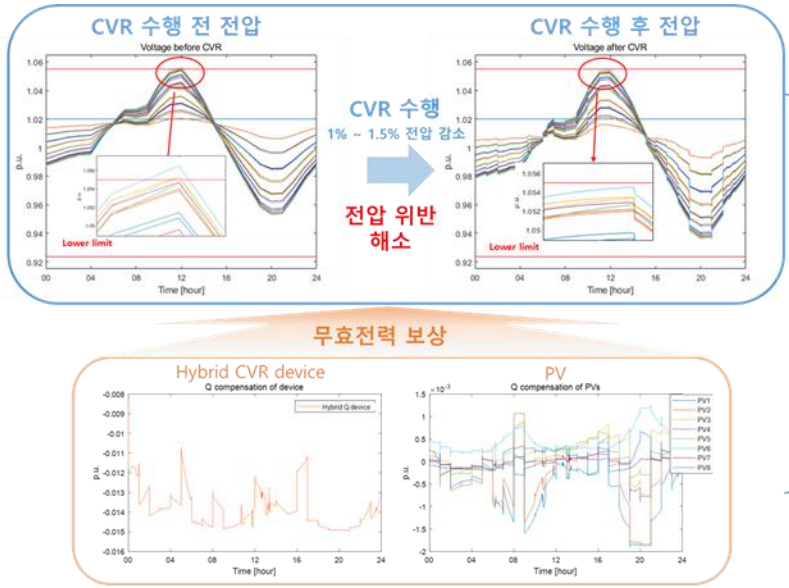


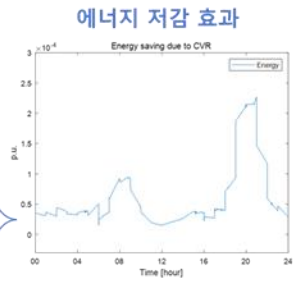




PHIL App. – Development of CVR Technology







에너지 저감	저감량 [kwh]
CVR 수행 전 일간 에너지 소모량	546.0
일간 부하 저감량	3.5
일간 손실 변화량	-2.1
일간 에너지 저감량	1.416
일간 에너지 저감율	0.26 %

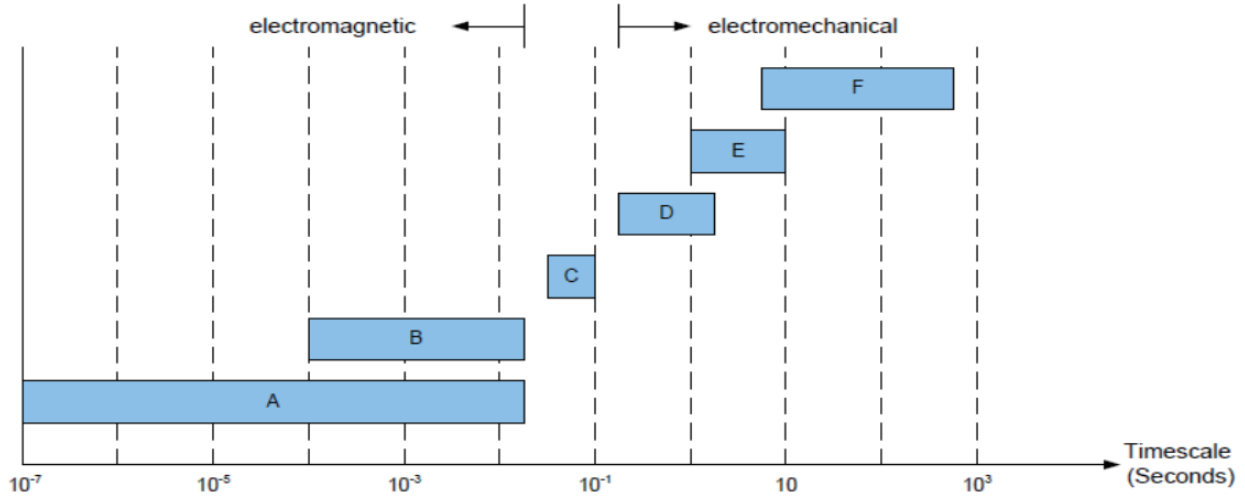
① 선로현황

② 장비현황

③ 제어결과

Power System Analysis

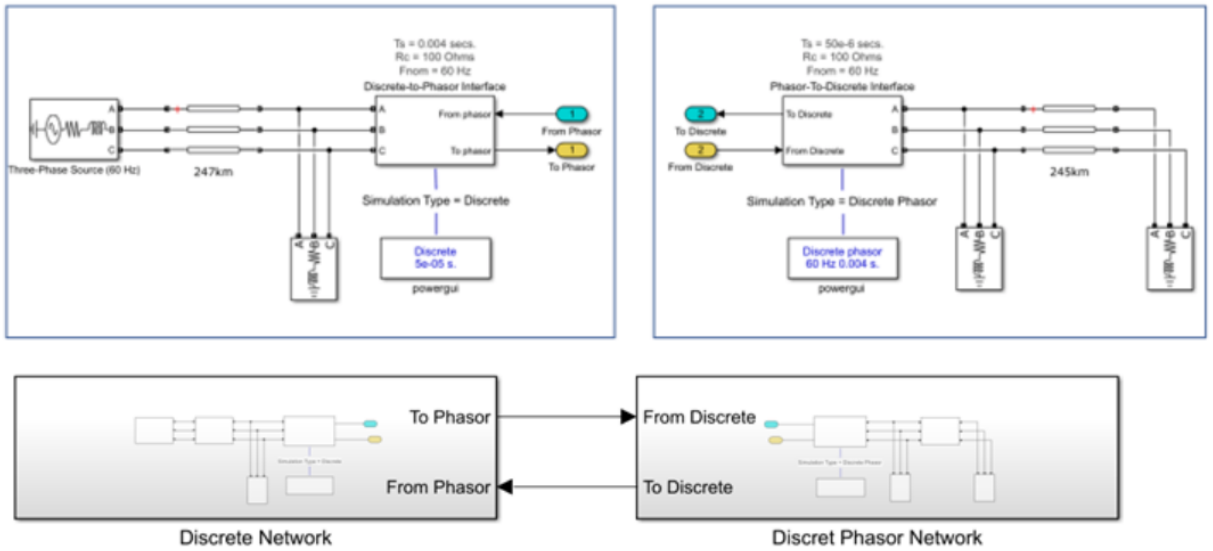
- 전기기계(Electro-Mechanical)해석 : TSA(Transient Simulation Analysis) 기반 해석
  - 정상분(positive-sequence) 모델에 대한 저주파수 영역에 국한된 해석
  - PSS/E, DSAT
- 전자기(Electro-Magnetic)해석 : EMT(Electro-Magnetic Transient) 기반 해석
  - 스위칭 과도현상, 전류서지, 전압 및 전류 파형 분석 등의 고주파수(수십kHz) 영역의 해석
  - PSCAD, EMTP

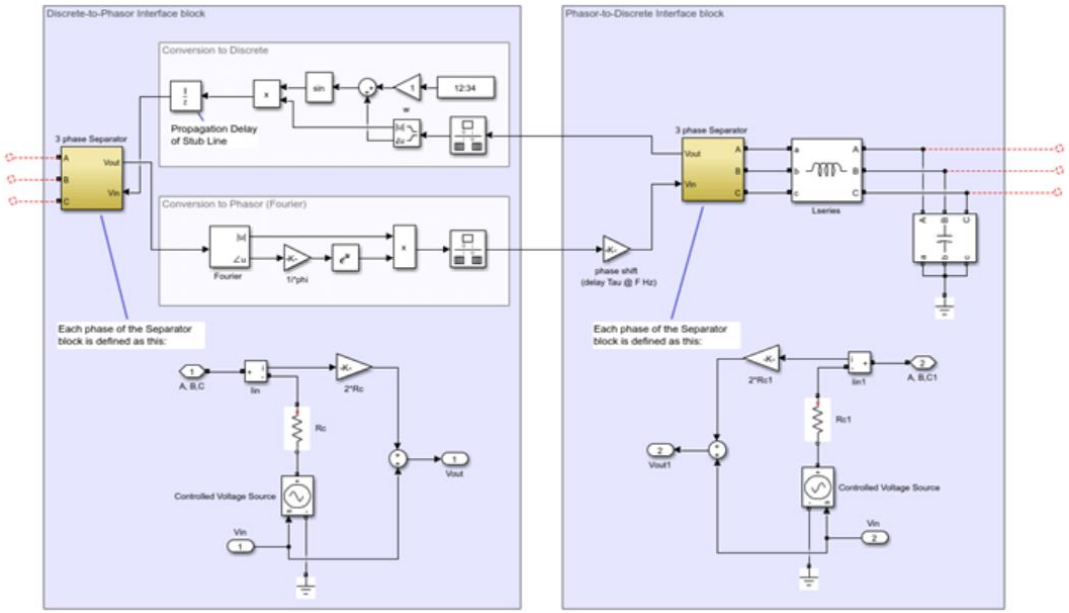


<전력계통 해석영역에 따른 Time Frame>

Hybrid Simulation For Large Power System Simulation

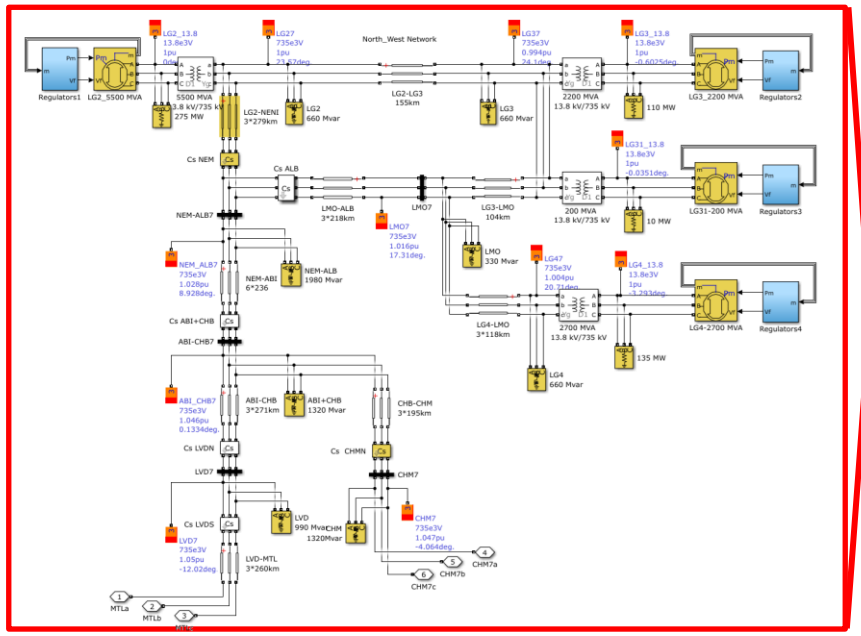
- Simulation method for large power system including power conversion system
  - EMT domain: High frequency dynamics(1~50us)
  - Phasor domain: Low frequency dynamics



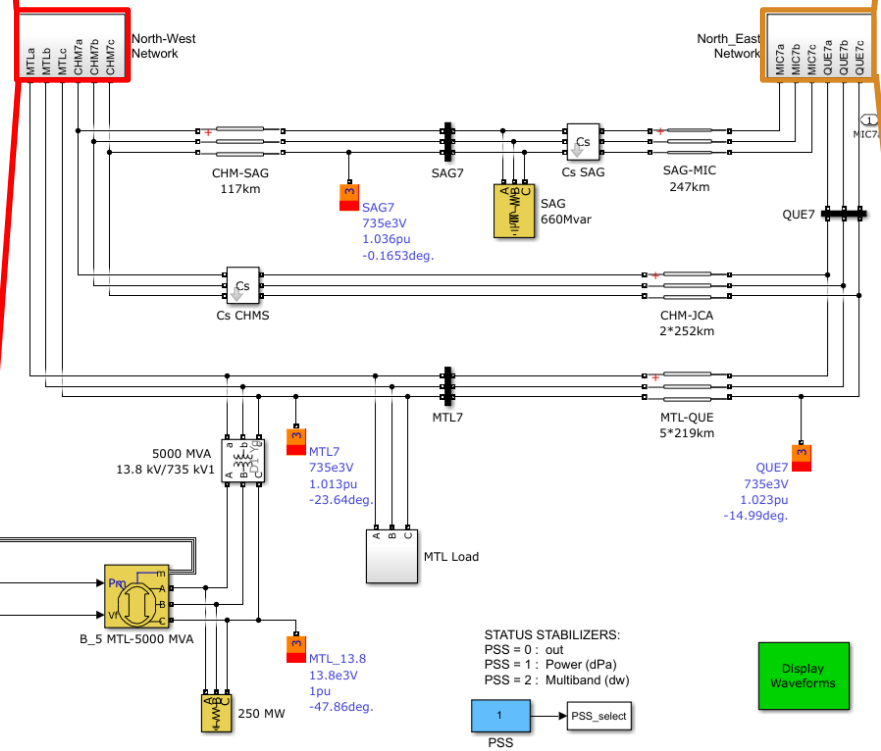


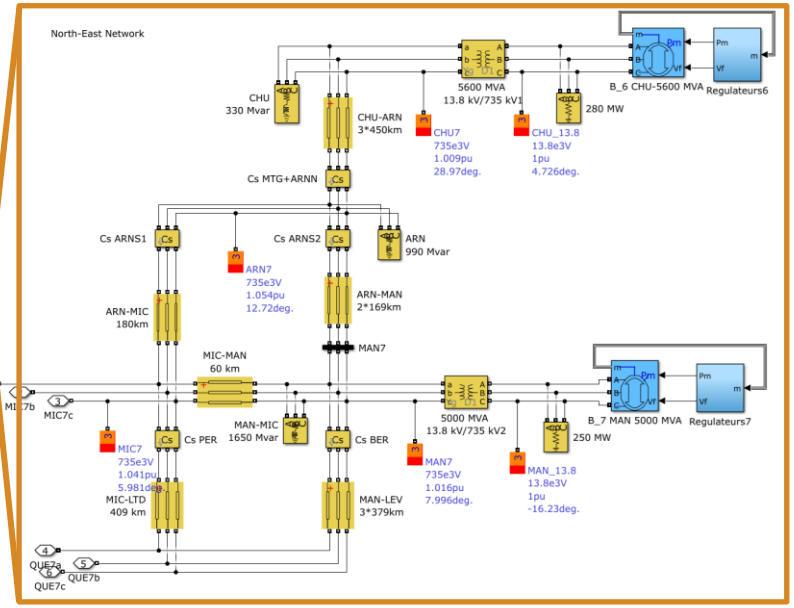
Large Power System Simulation

- EMT vs. Phasor
- 29-Bus, 7-Power Plant Network



<North-West Network>



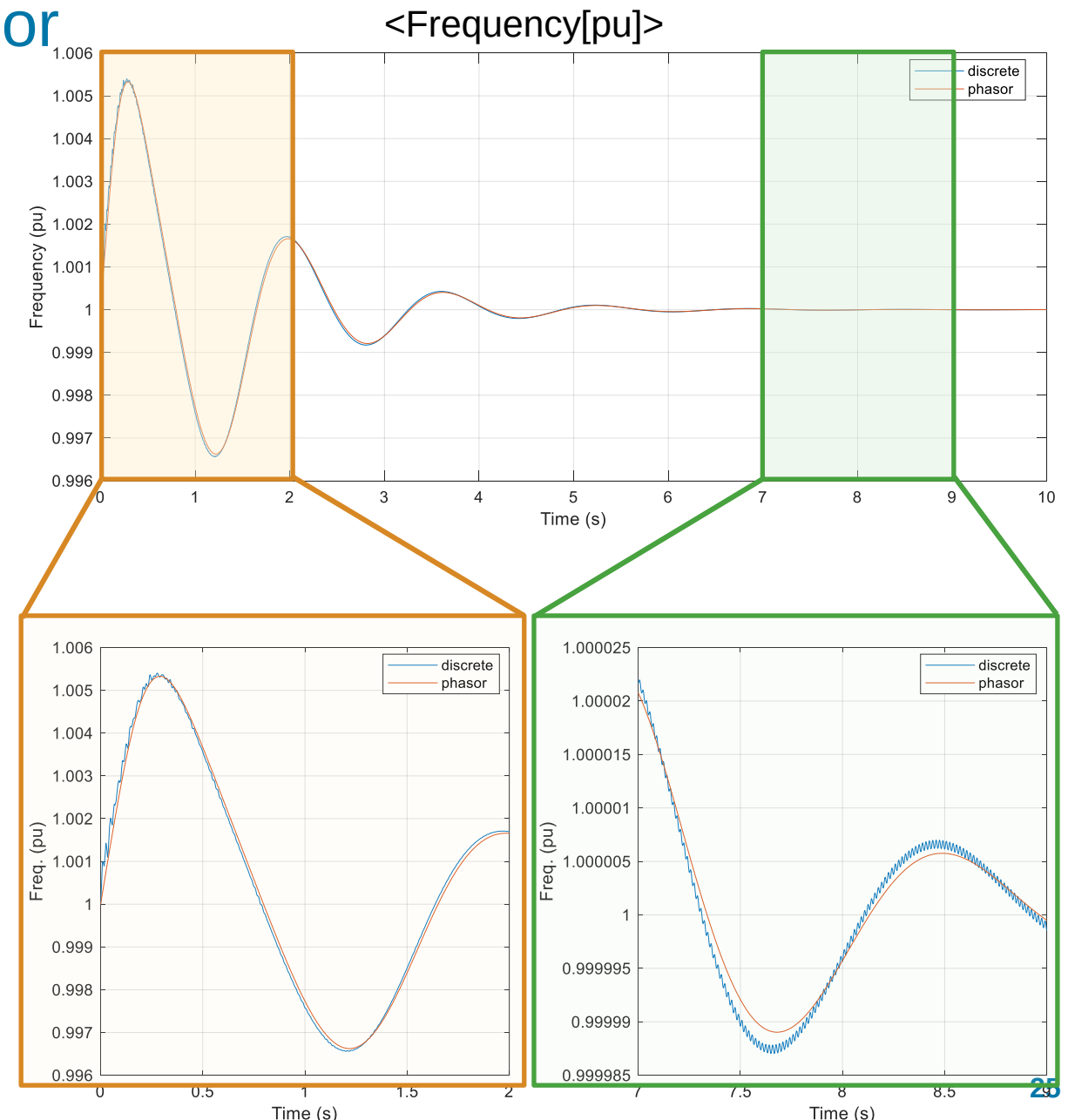


<North-East Network>

Comparison between EMT vs Phasor

- EMT Simulation(Discrete):
  - Sampling time: 10us; Simulation time: 10s
  - Total time: 368.670s
- Phasor Simulation(Phasor)
  - Sampling time: 1ms; Simulation time: 10s
  - Total time: 3.292

system_29bus_fullDiscrete	368.670
Discrete	298.506
North-West Network	124.658
North_East Network	65.358
powergui	27.735
MTL Load	23.287
B_5 MTL-5000 MVA	15.032
system_29bus_fullPhasor	3.292
Phasor	2.438
North-West Network	1.086
North_East Network	0.513
powergui	0.293
B_5 MTL-5000 MVA	0.203
Regulators5	0.126
Subsystem	0.093
Three-Phase Program…	0.083
MTL Load	0.036



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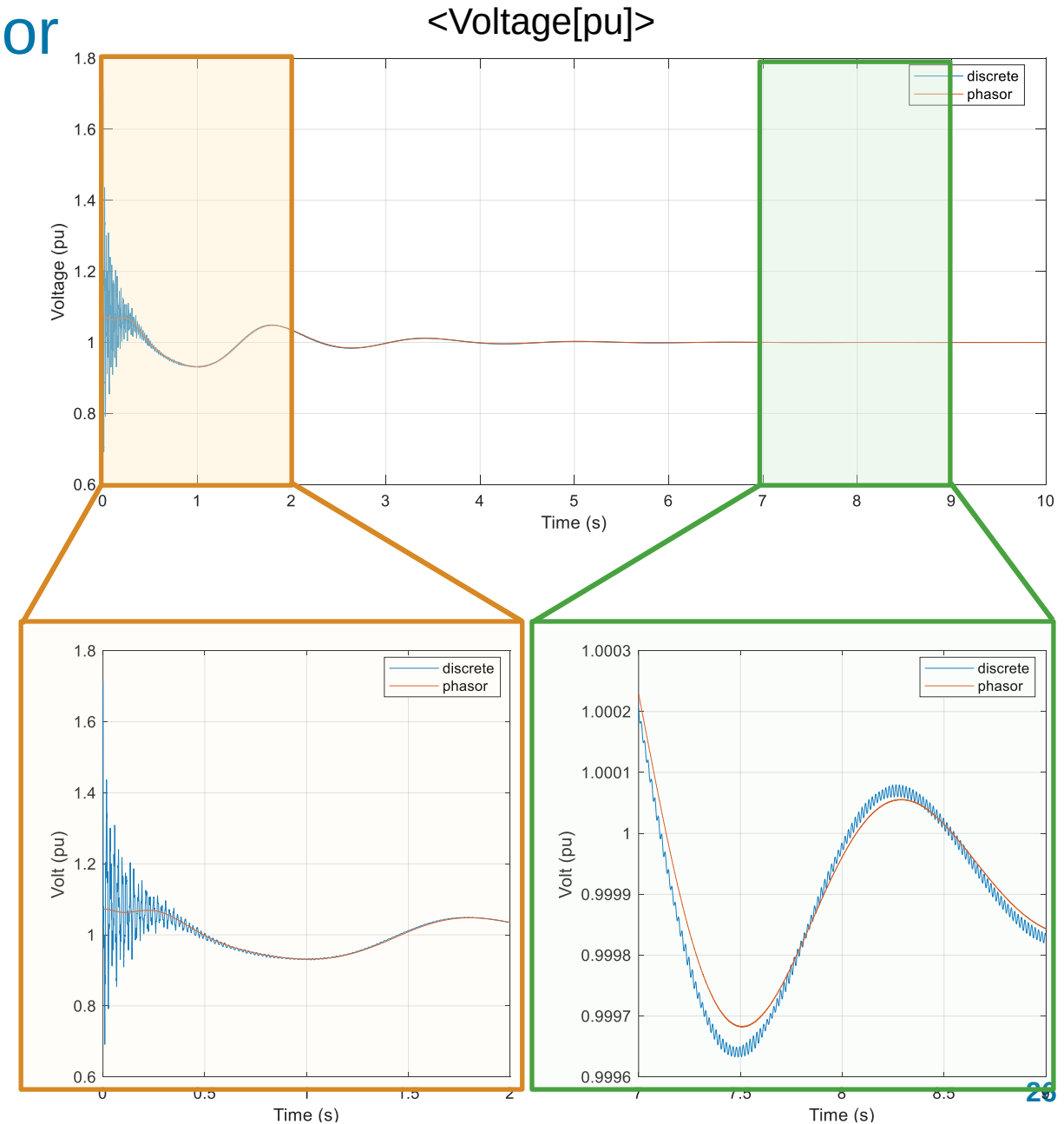
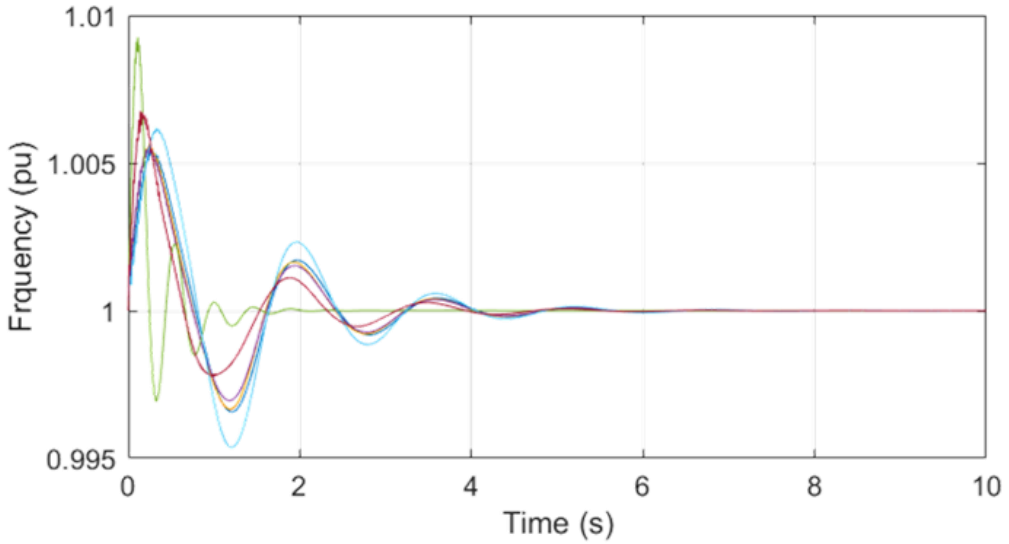
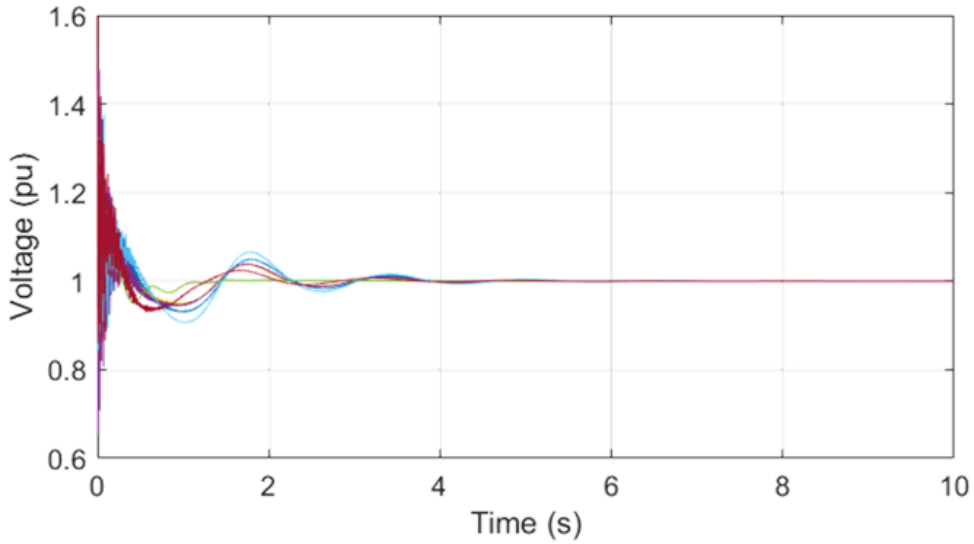
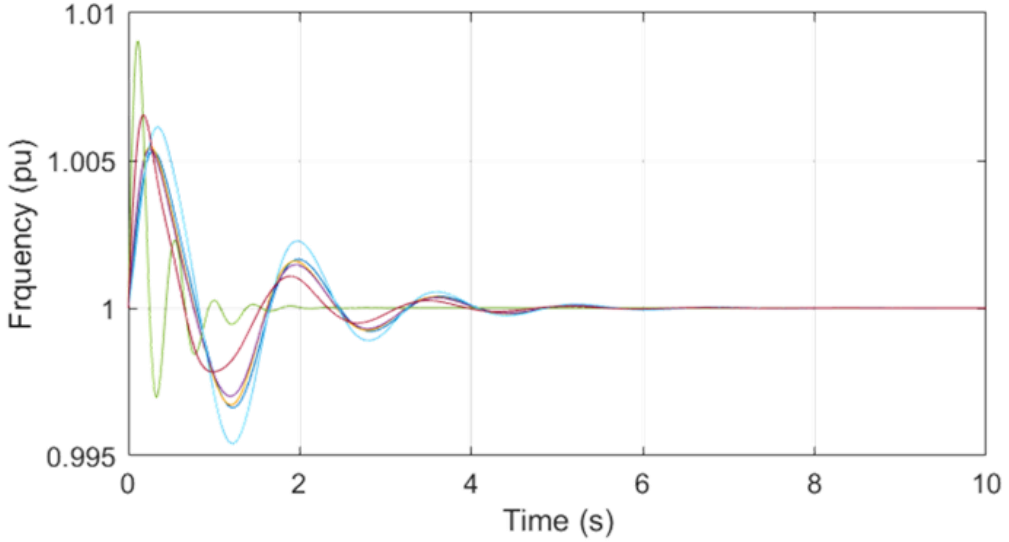
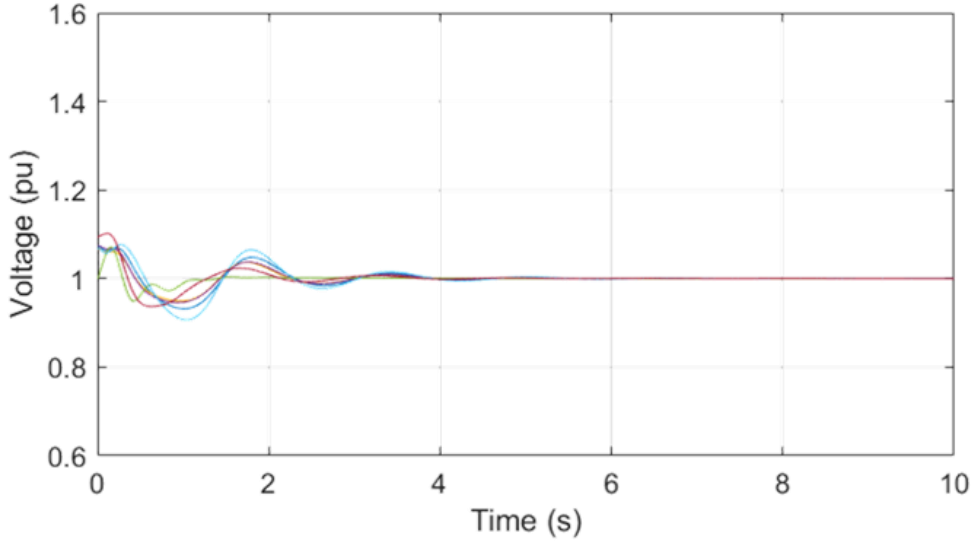


Comparison between EMT vs Phasor



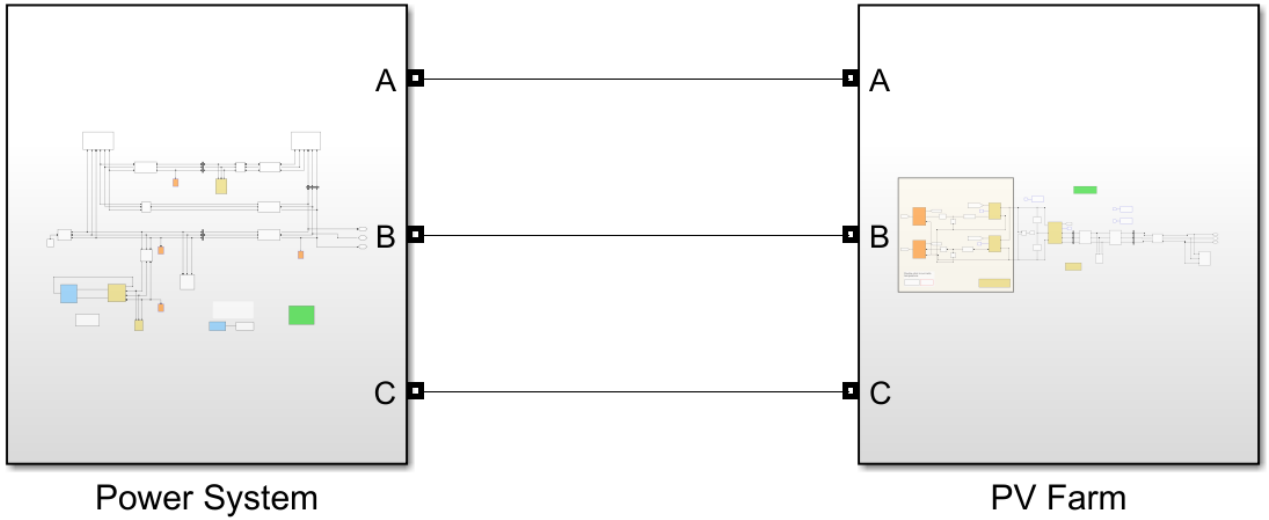






Large Power System + Power Conversion System

- Full EMT simulation
  - 29-bus system + PV farm(Power electronics, AC/DC inverter(1) + DC/DC converter(2))
  - Sampling Time: 10us
  - Simulation Time: 10s

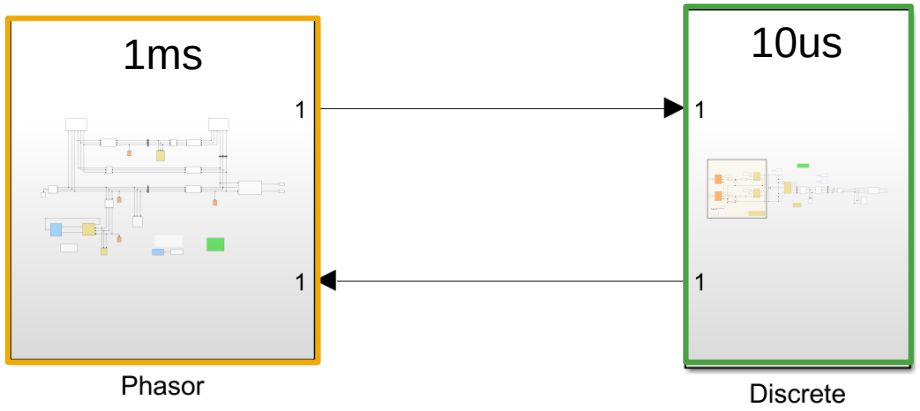


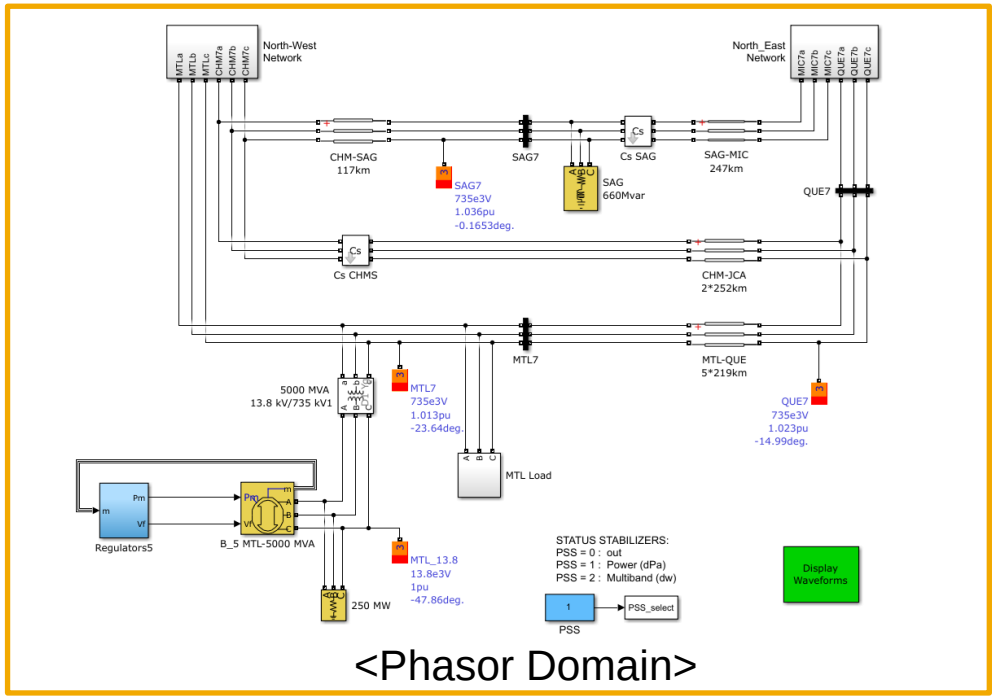
system_29bus_PVfarm_full···		1327.731
Phasor		1014.726
PV Farm		232.193

Hybrid Simulation For Large Power System Simulation

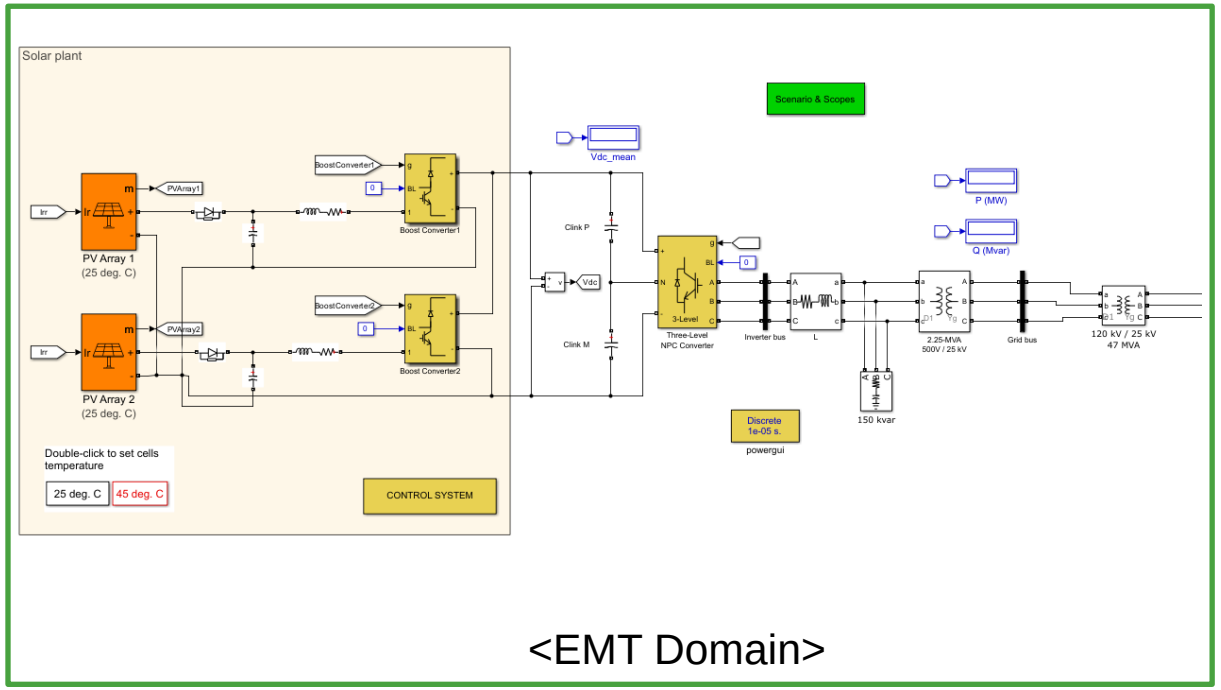
- Hybrid Simulation
  - Phasor Simulation: 29-bus system → 1ms
  - EMT simulation: PV Farm(about 2kHz switching) → 10us

system_29bus_hybrid		22.015
Discrete		17.180
Phasor		1.079





<Phasor Domain>



<EMT Domain>

Hybrid Simulation For Large Power System Simulation

- Hybrid Simulation
  - Phasor Simulation: 29-bus system → 1ms
  - EMT simulation: PV Farm(about 2kHz switching) → 10us

system_29bus_hybrid		22.015
Discrete		17.180
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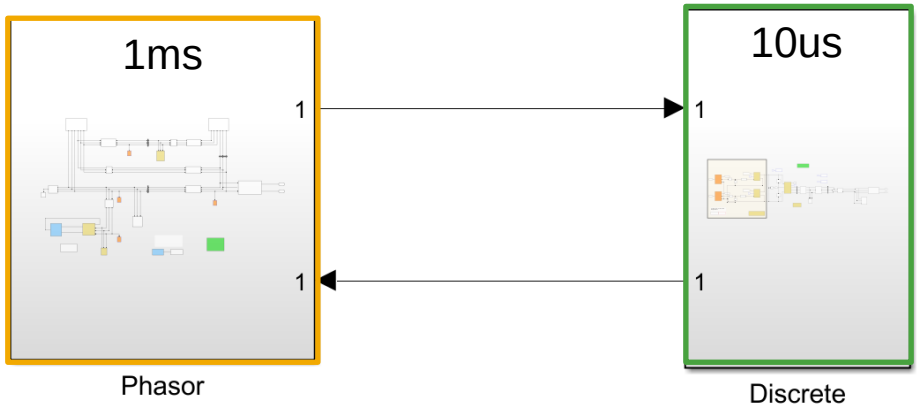
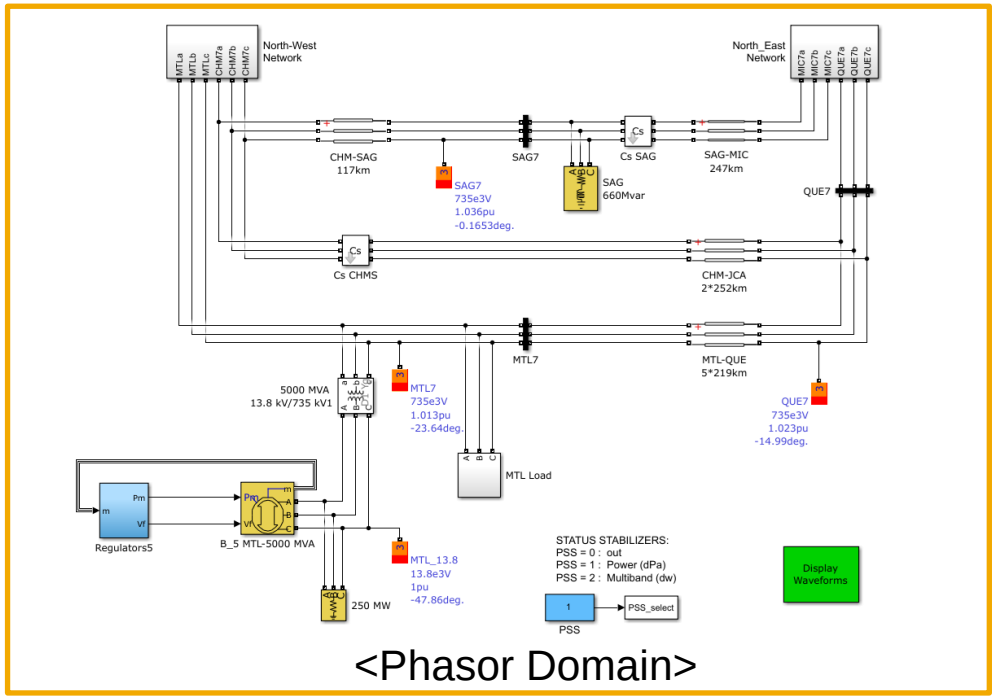
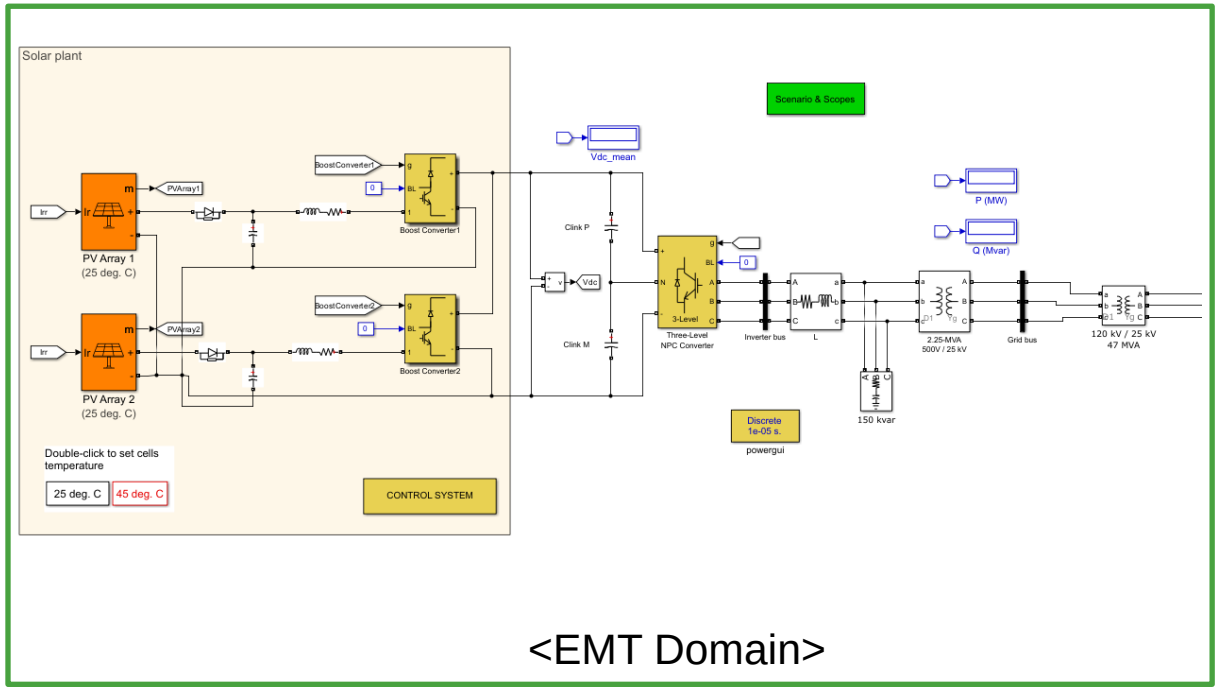




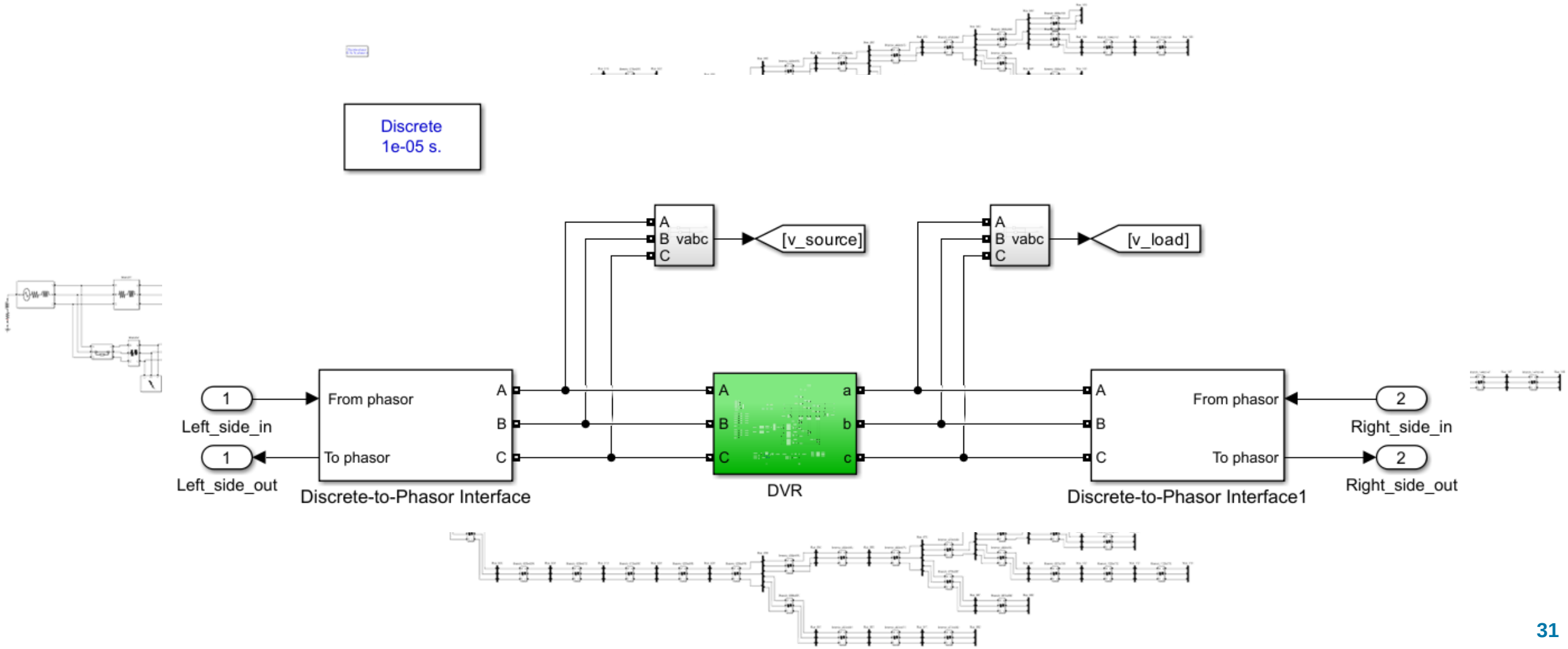
<Phasor Domain>



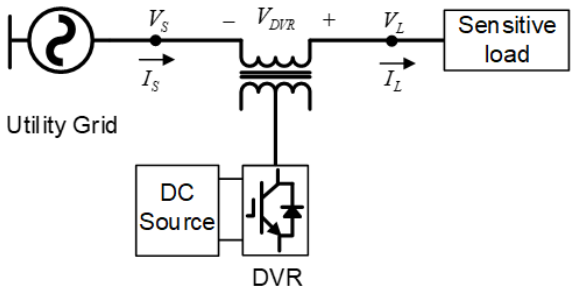
<EMT Domain>

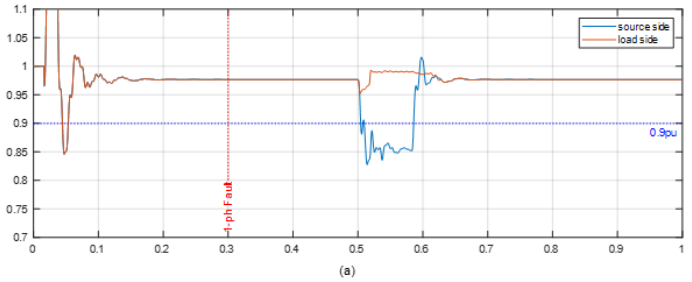
Hybrid Simulation App. – Voltage Compensator

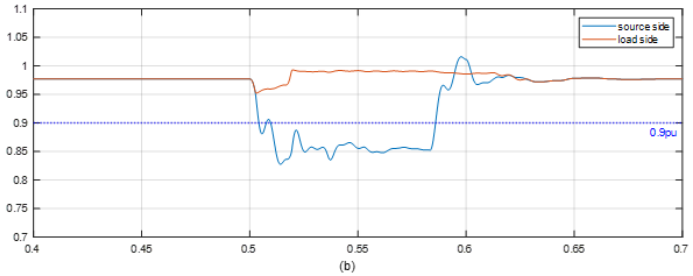
- 144-bus system including variable renewable system, fuel cell, and voltage compensator

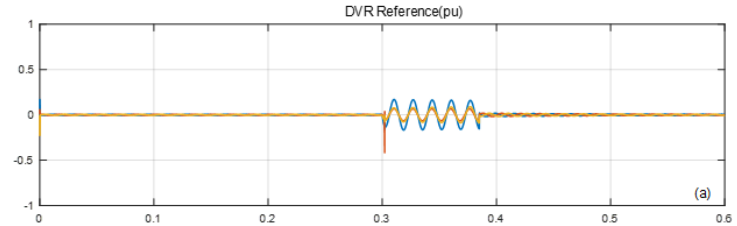


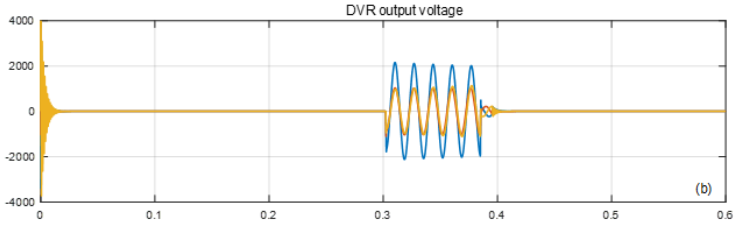
Hybrid Simulation App. – Voltage Compensator

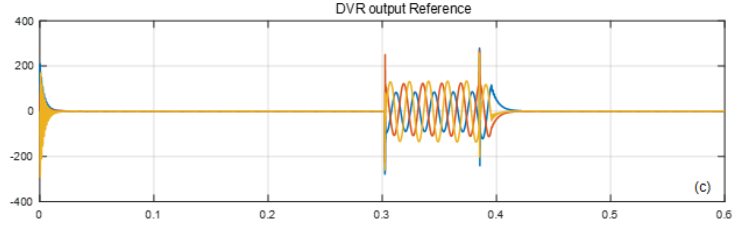


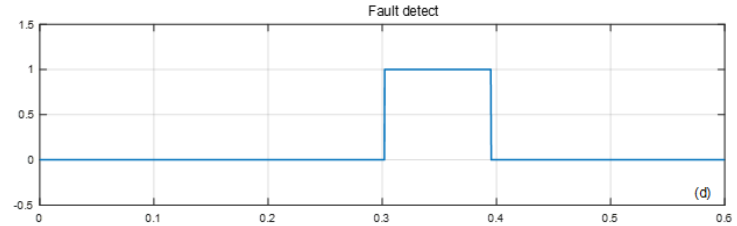


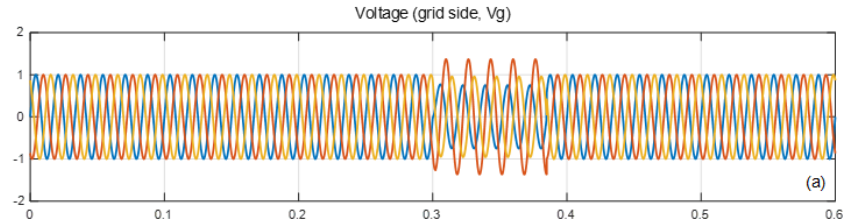


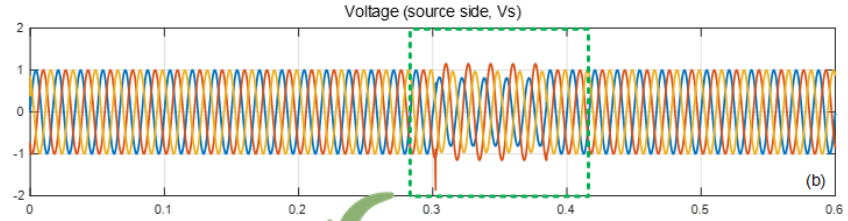


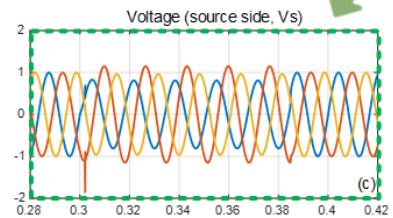


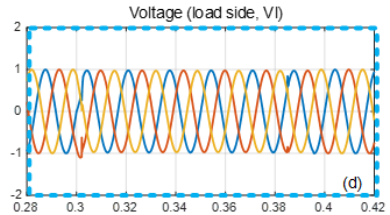


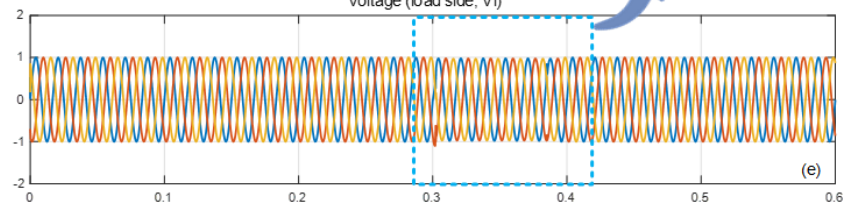


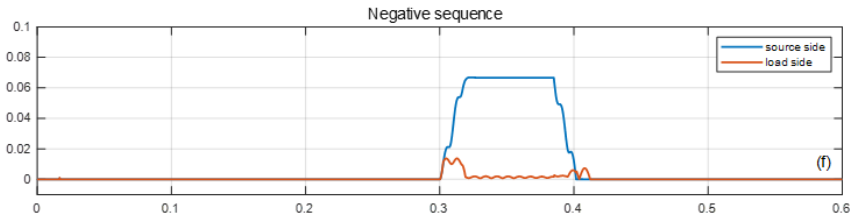




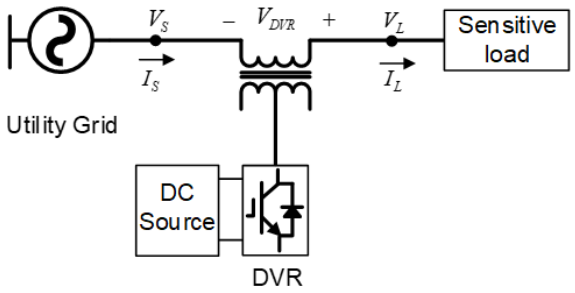


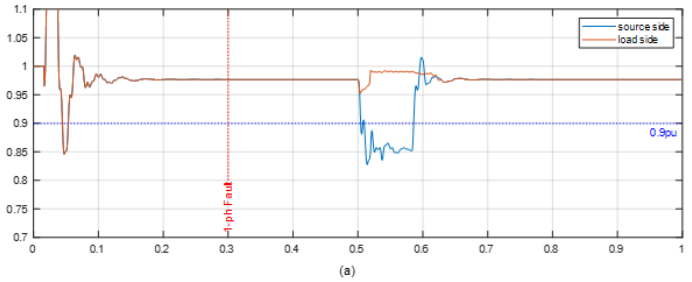


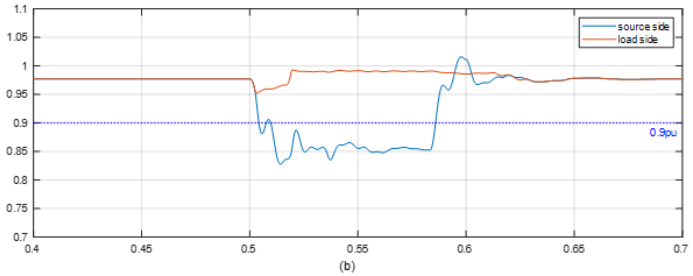


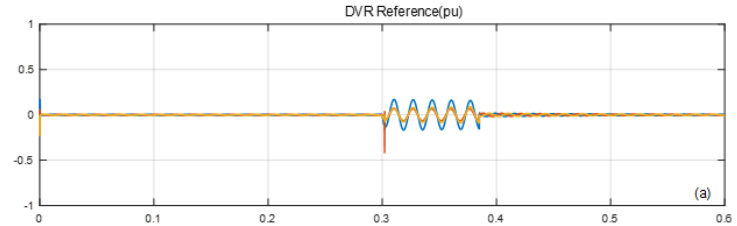


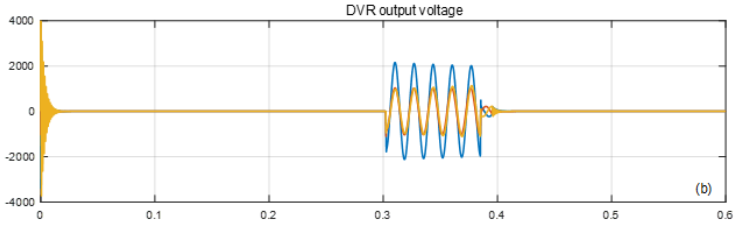
Hybrid Simulation App. – Voltage Compensator

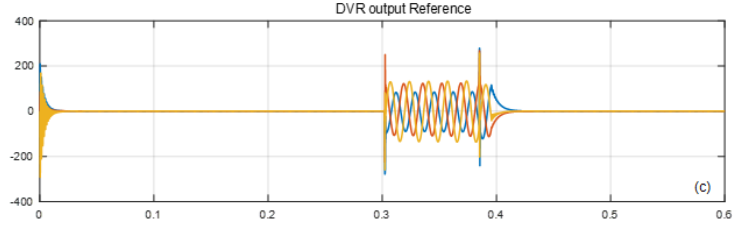


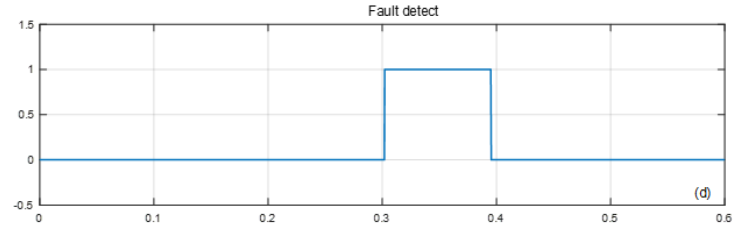


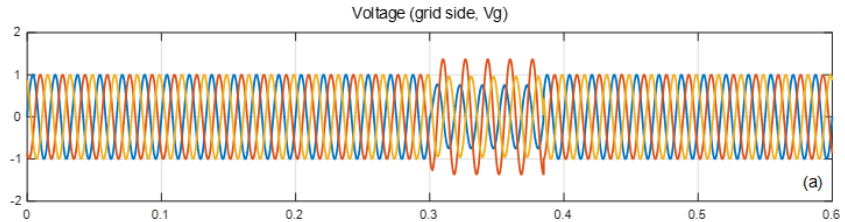


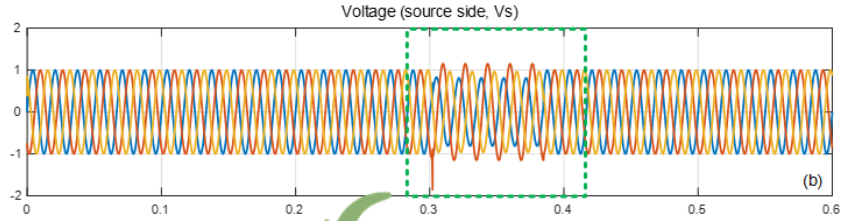


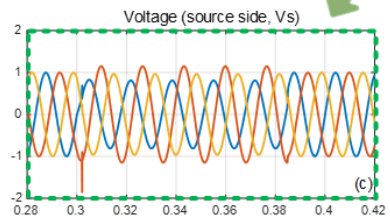


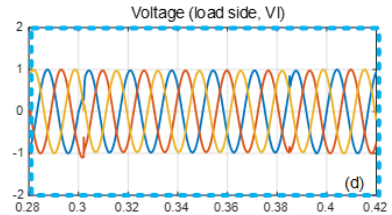


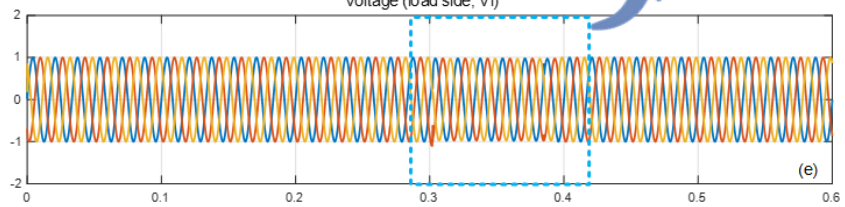


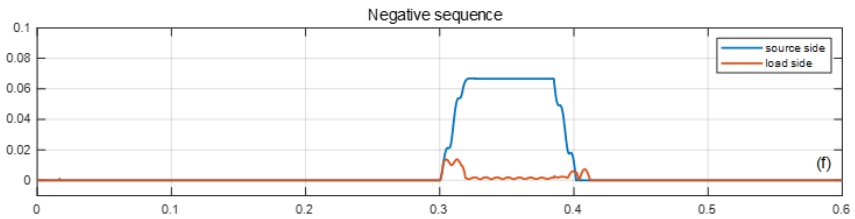








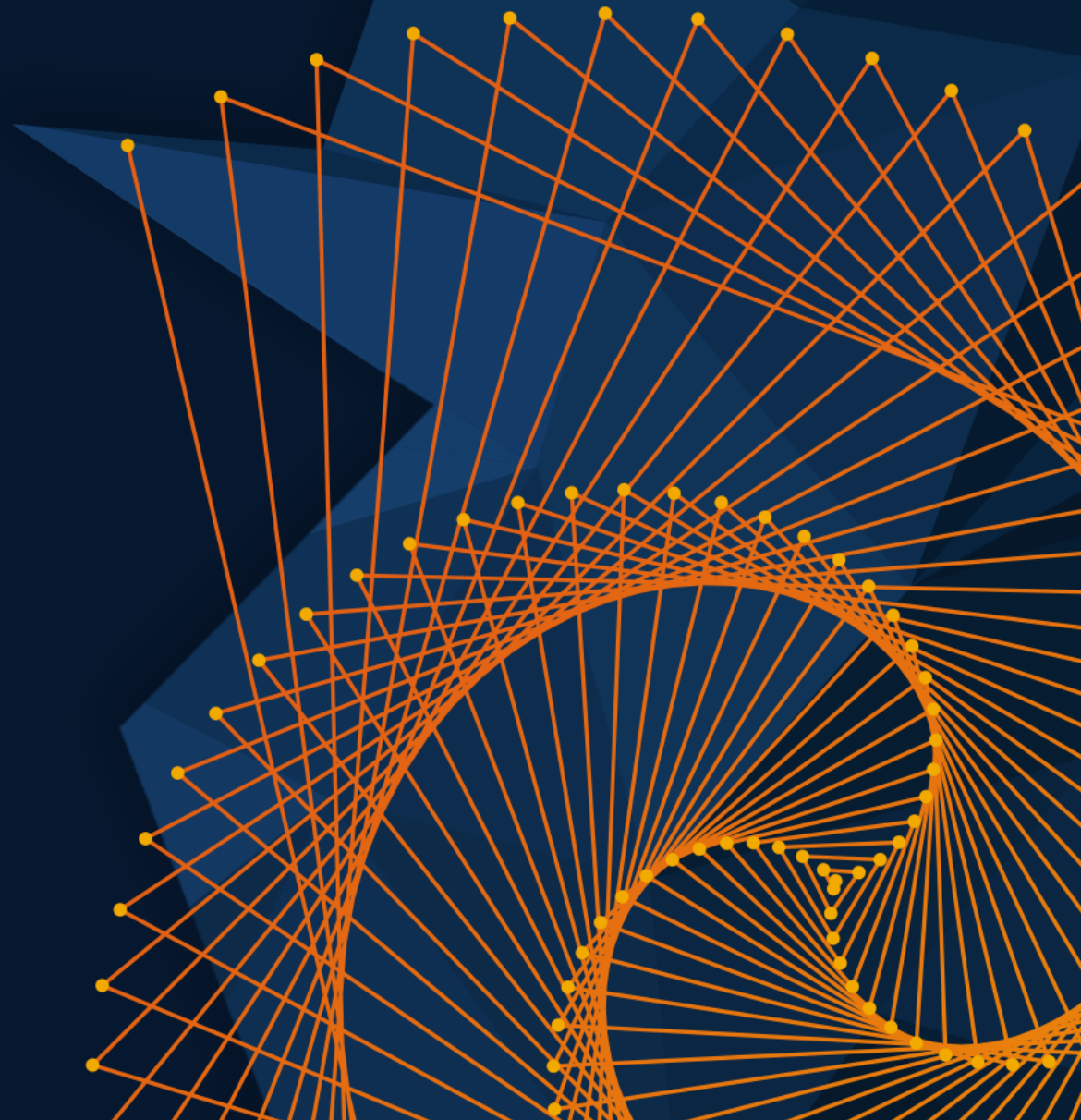




Conclusions

- HILS 환경에서의 전력시스템 기술 개발
  - RCP: 플랜트모델을 실제 하드웨어로 사용하며 제어기를 시뮬레이터로 이용하여 제어기의 feasibility 검토단계
  - CHIL: 플랜트모델을 시뮬레이터로 구성하며 테스트하고자 하는 제어기를 실제 H/W로 구축하여 제어기의 성능 및 고도화 단계
  - PHIL: 테스트하고자 하는 장비를 실제 H/W로 구축하고, 테스트계통을 시뮬레이터에 구축하여 테스트하고자 하는 장비의 성능 및 적용효과 검토단계
- IBR이 포함된 대규모계통 해석을 위한 Hybrid 시뮬레이션
  - 시뮬레이션 목적에 따라 시뮬레이션 도메인을 나누어 시뮬레이션하는 기법
  - 시뮬레이션 속도 향상이 가능하며 HILS 구축에 용이함

MATLAB EXPO



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