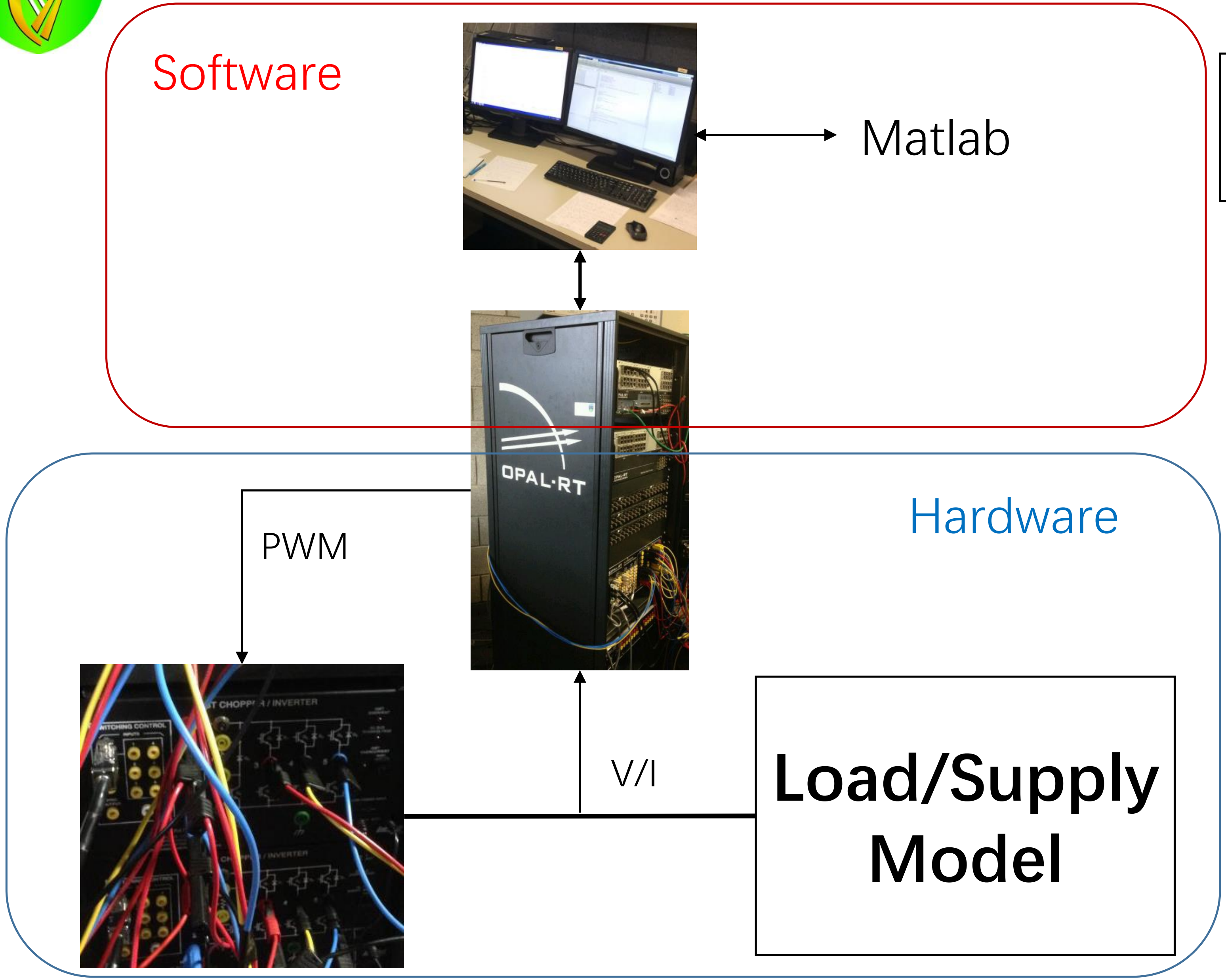
Hardware in the Loop Real-time Simulation Platform in UCD

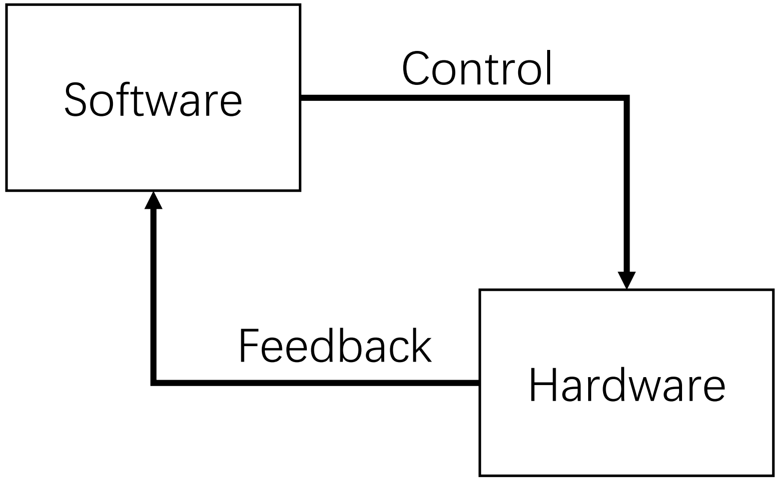
Junru Chen

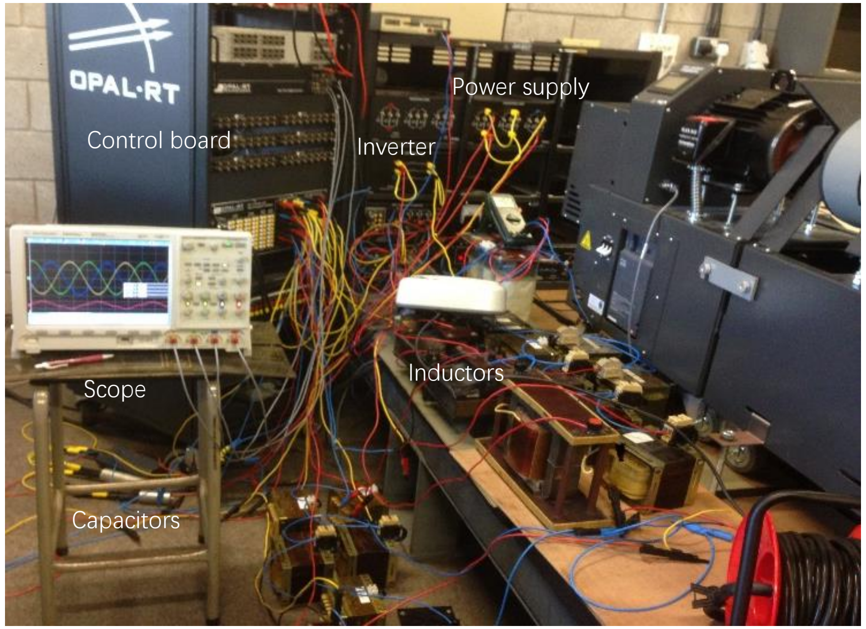
Outline

- **UCD Hardware Lab**
- **Load Determination**

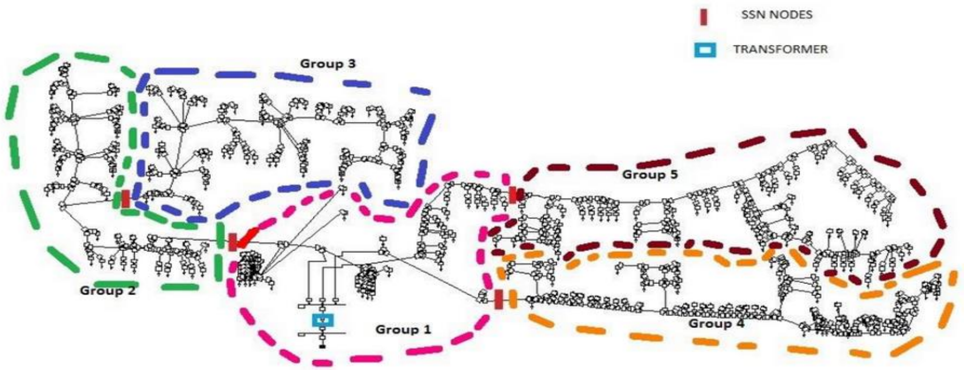
Hardware in the Loop Real-time Simulation

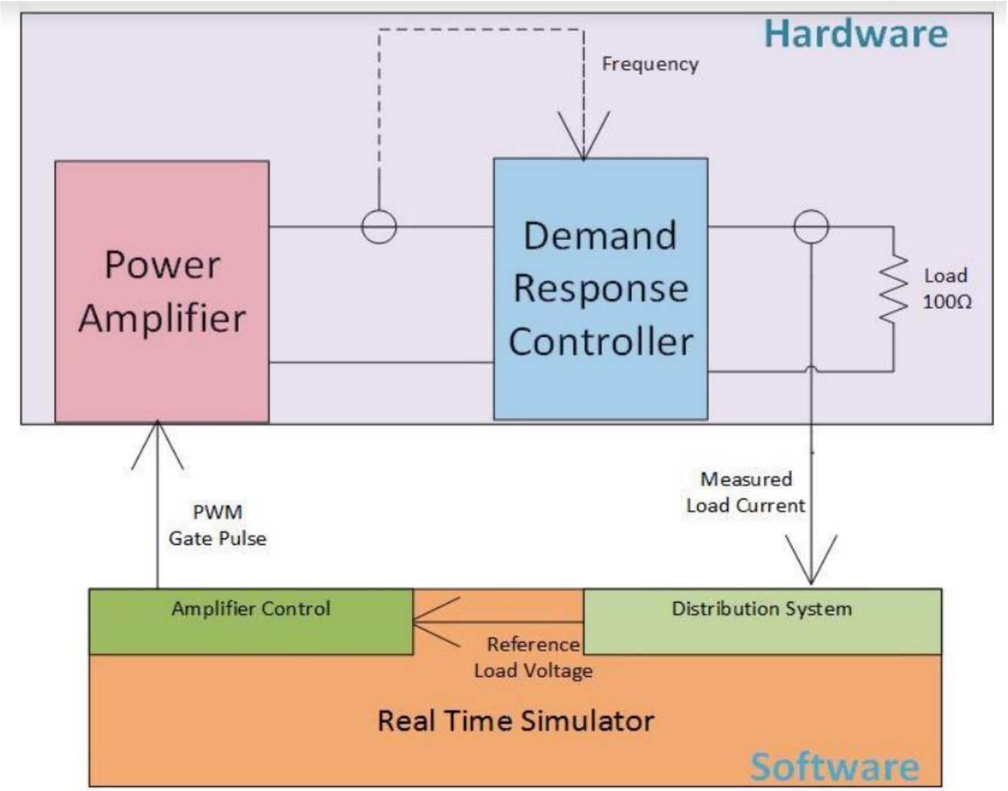






UCD Hardware Lab-Microgrid

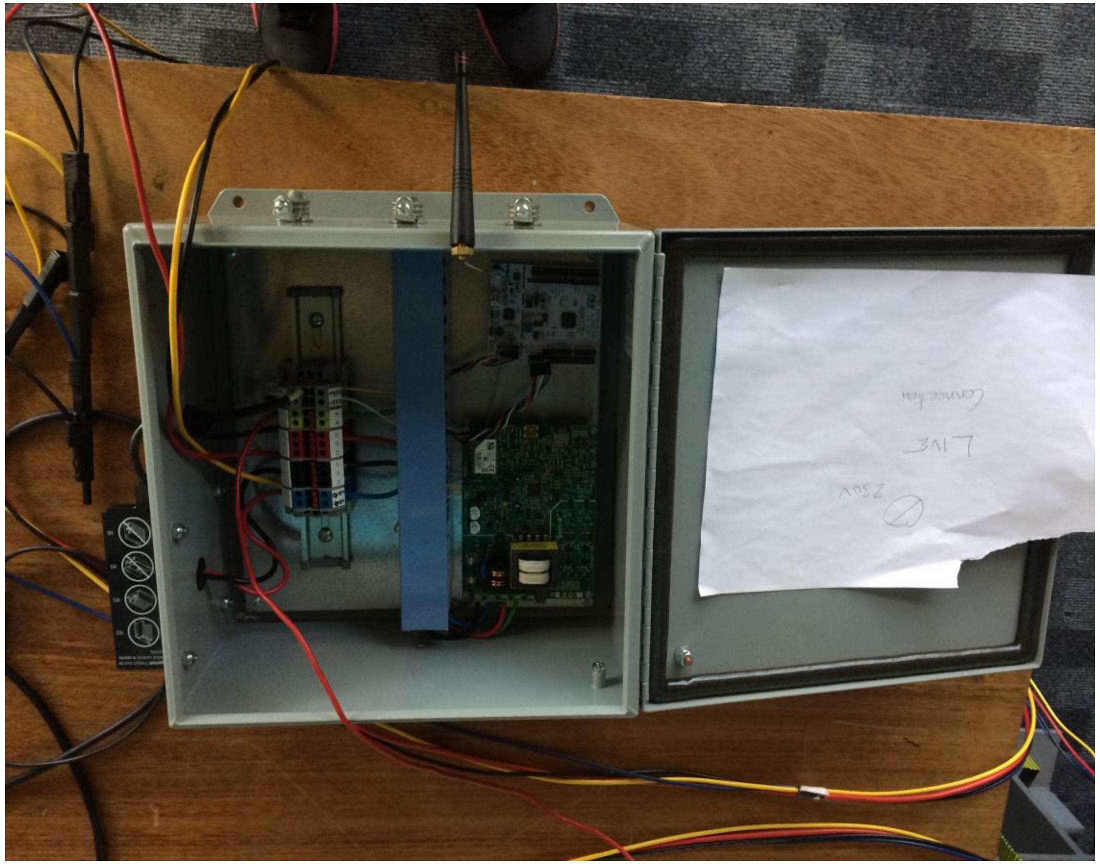




ENWL Distribution grid in Manchester:

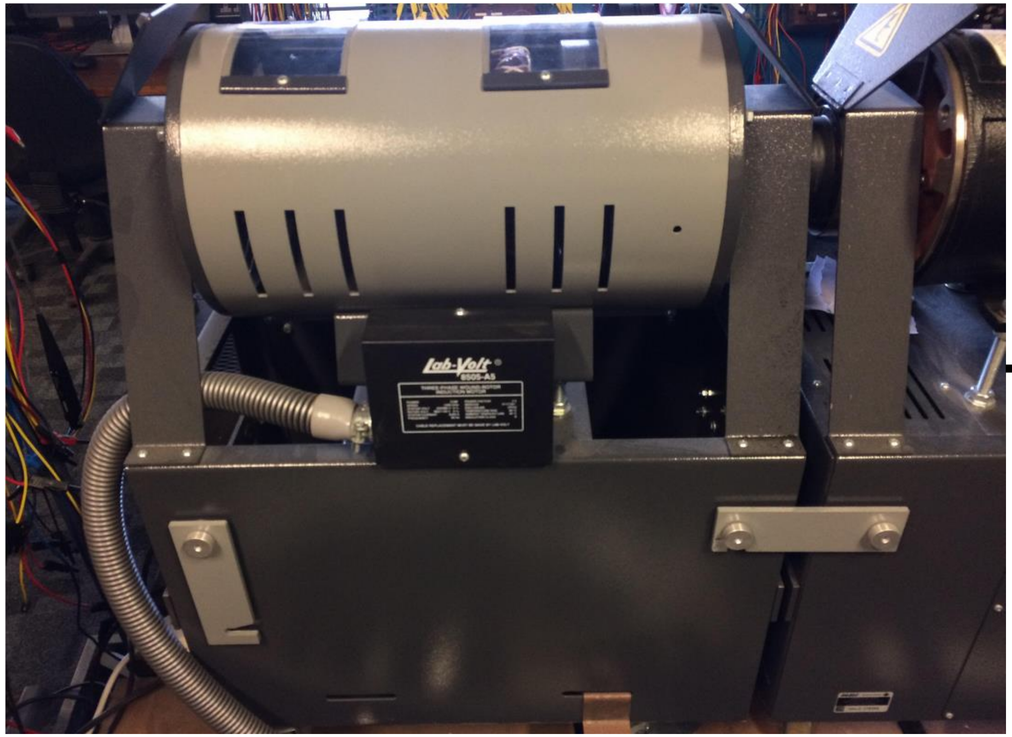
Three feeder with 330 houses/6350 nodes

Fed by 13.8/0.4 kV DY Transformer



Demand Amplifier

UCD Hardware Lab-Wind Turbine



Wind Emulator

Double Fed Induction Generator

UCD Hardware Lab-Projects

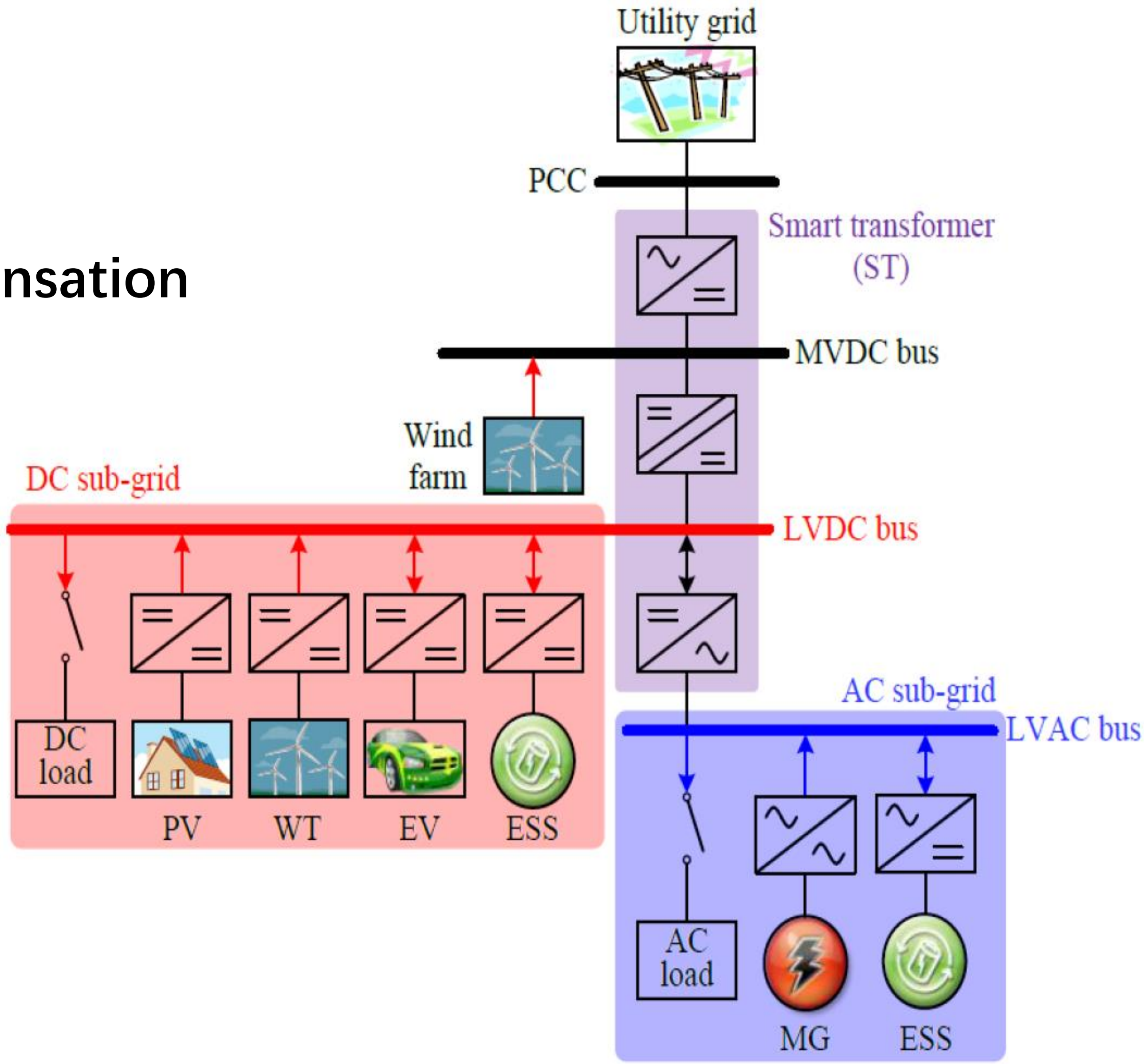
- HVDC (Jonathan Ruddy)
- Demand Control (Ismail Ibrahim)
- Smart Transformer (Junru Chen)
- Virtual Synchronous Machine (Junru Chen, Ismail Ibrahim)

Smart Transformer

MVAC/MVDC:
Voltage support/reactive power compensation

MVDC/LVDC:
Energy integration

LVDC/LVAC:
distribution system voltage regulation



Load Determination

- **Increase of the Distributed Energy Source**

Constant impedance dominated load becomes to constant power load
Conversional Voltage Reduction (CVR) may not be effective which only reduces voltage.

- **Load shedding**

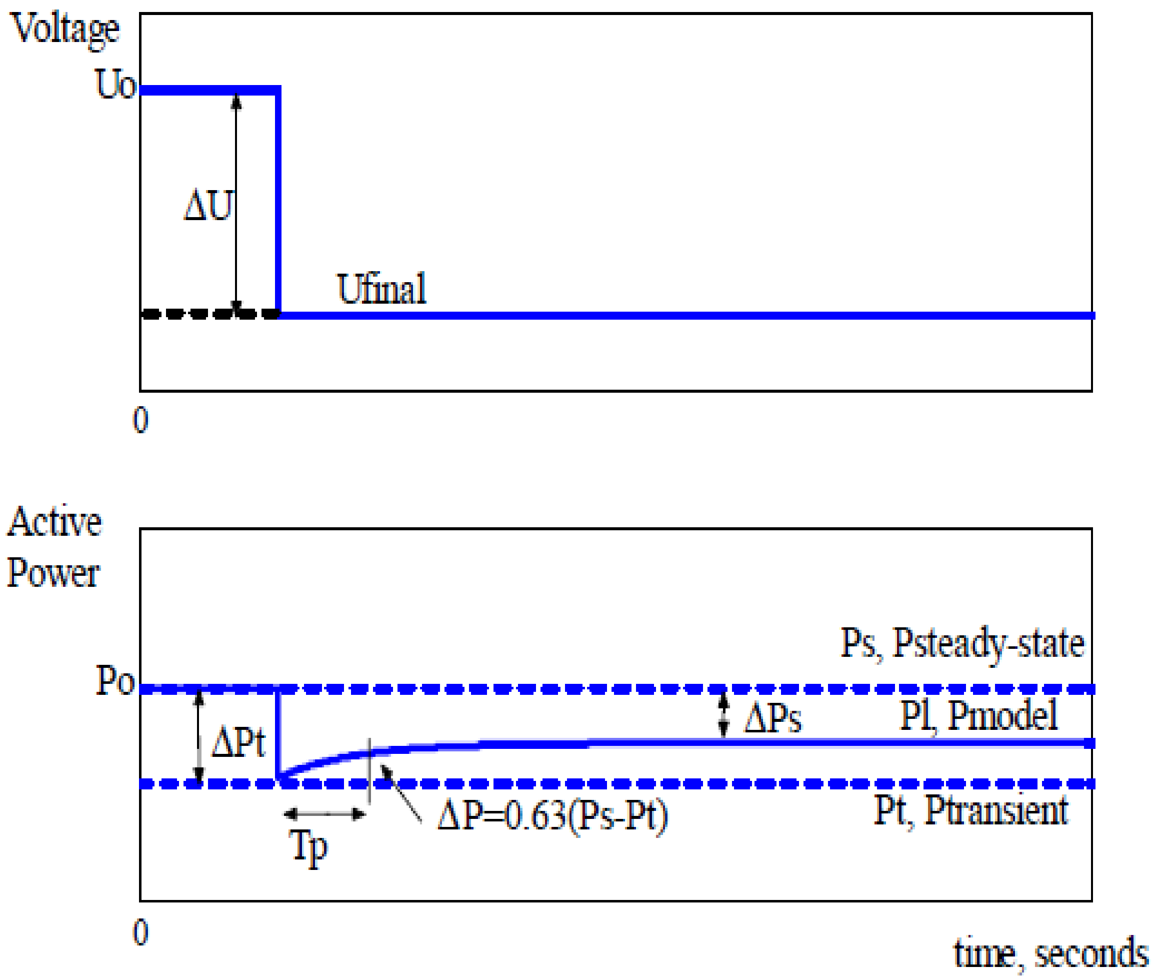
Not only for the supply & demand balance
But also for the maximum flow of Smart Transformer

Load Determination

Exponential Dynamic Load

$$T_p \frac{dP_r}{dt} + P_r = P_0\left(\frac{U}{U_0}\right)^{\alpha_s} - P_0\left(\frac{U}{U_0}\right)^{\alpha_t} = P_s - P_t$$

$$P_l = P_r + P_0\left(\frac{U}{U_0}\right)^{\alpha_t} = P_r + P_t$$



Simplify:

$$\boldsymbol{P_l(t) = P_t + (P_s - P_t)\left(1 - e^{-t/T}\right) = P_s + (P_t - P_s)e^{-t/T}}$$

Where: $T_p \in (80{,}200)$

$\alpha_s \in (0.3{,}1.2)$

$\alpha_t \in (1.3{,}2.1)$

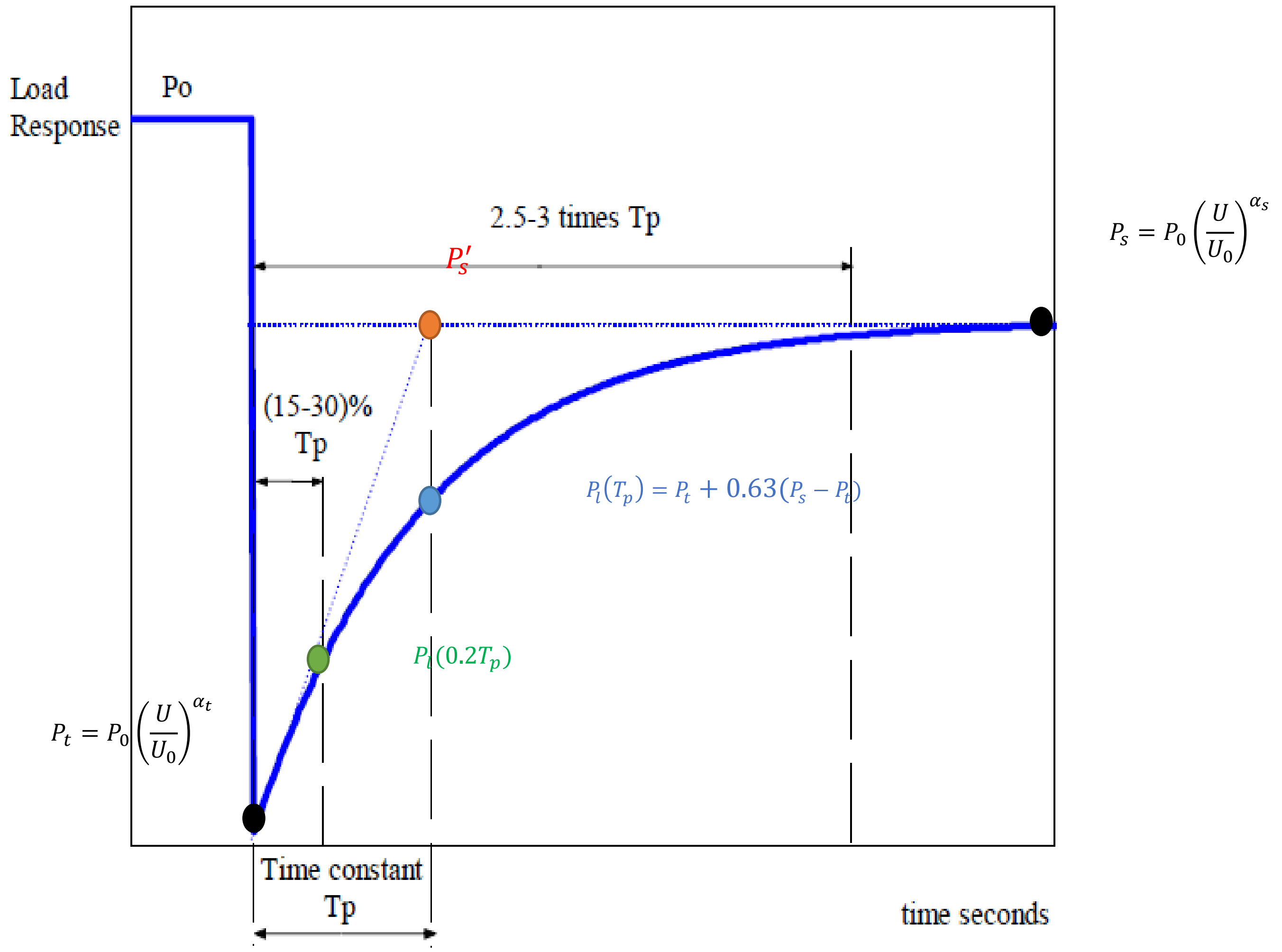
Load Determination

The 37% Method

$$P_s = P_s' = \frac{P_l(T_P) - 0.37P_t}{0.63}$$

The Initial Slope Method

$$P_s = P_s' \approx \frac{P_l(0.2T_P) - P_t}{0.2} + P_t$$



Load Determination

Voltage Sensitivity:
The percent of power change with 1% of voltage reduction

$$VS = \frac{\dfrac{P_k - P_{k-1}}{P_{k-1}}}{\dfrac{U_k - U_{k-1}}{U_{k-1}}} = \frac{(P_0 - P_l)/P_0}{\Delta U\%}$$

Where P_0 is the power before voltage change
P_l is the power after voltage change
$\Delta U\%$ is the purposely voltage change

Load Determination

Load Determination Strategy:

1) Purposely voltage change

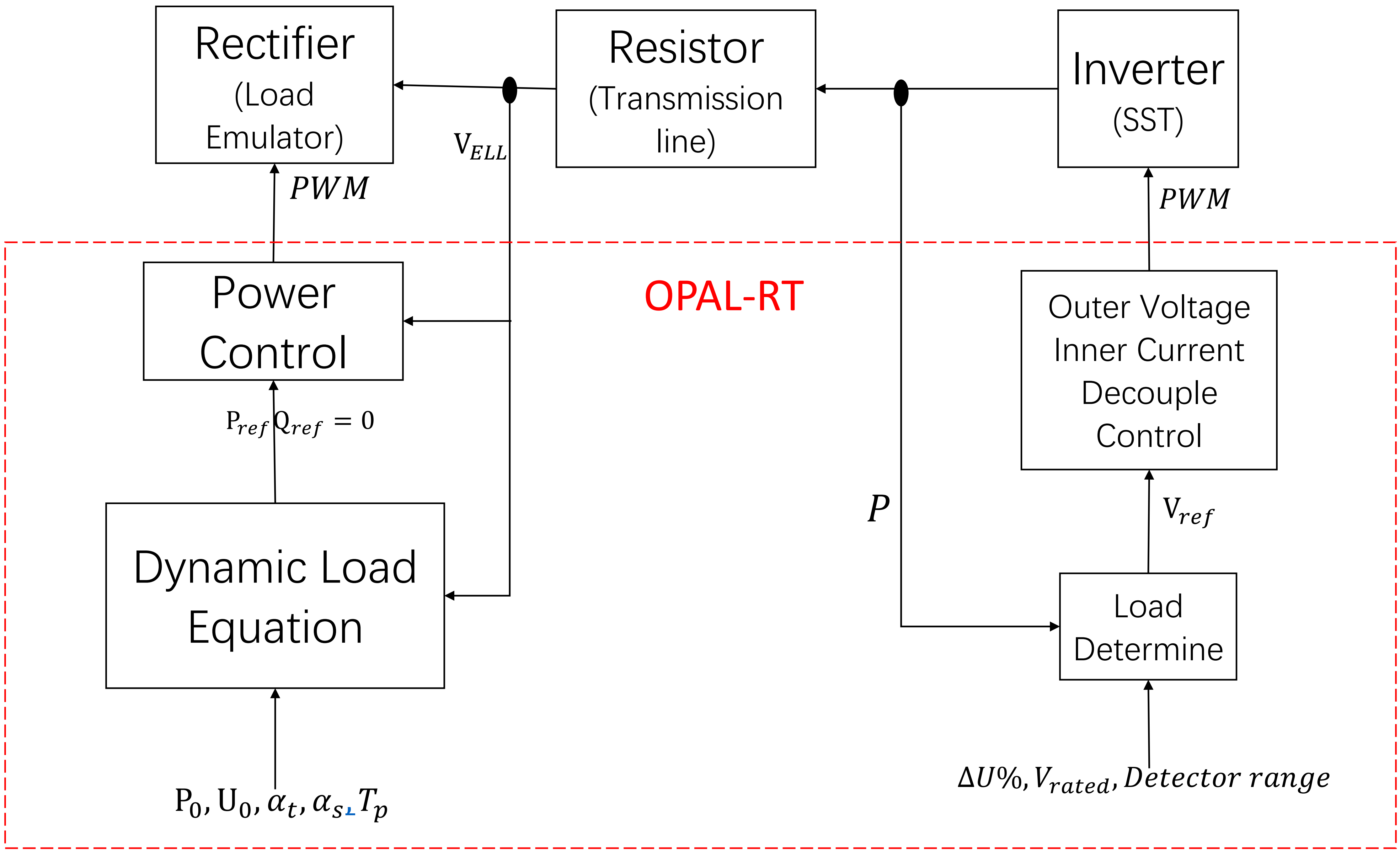
2) Calculate VS (if wrong, rest)

3) Find the min/max VS as P_t (if wrong, reset)

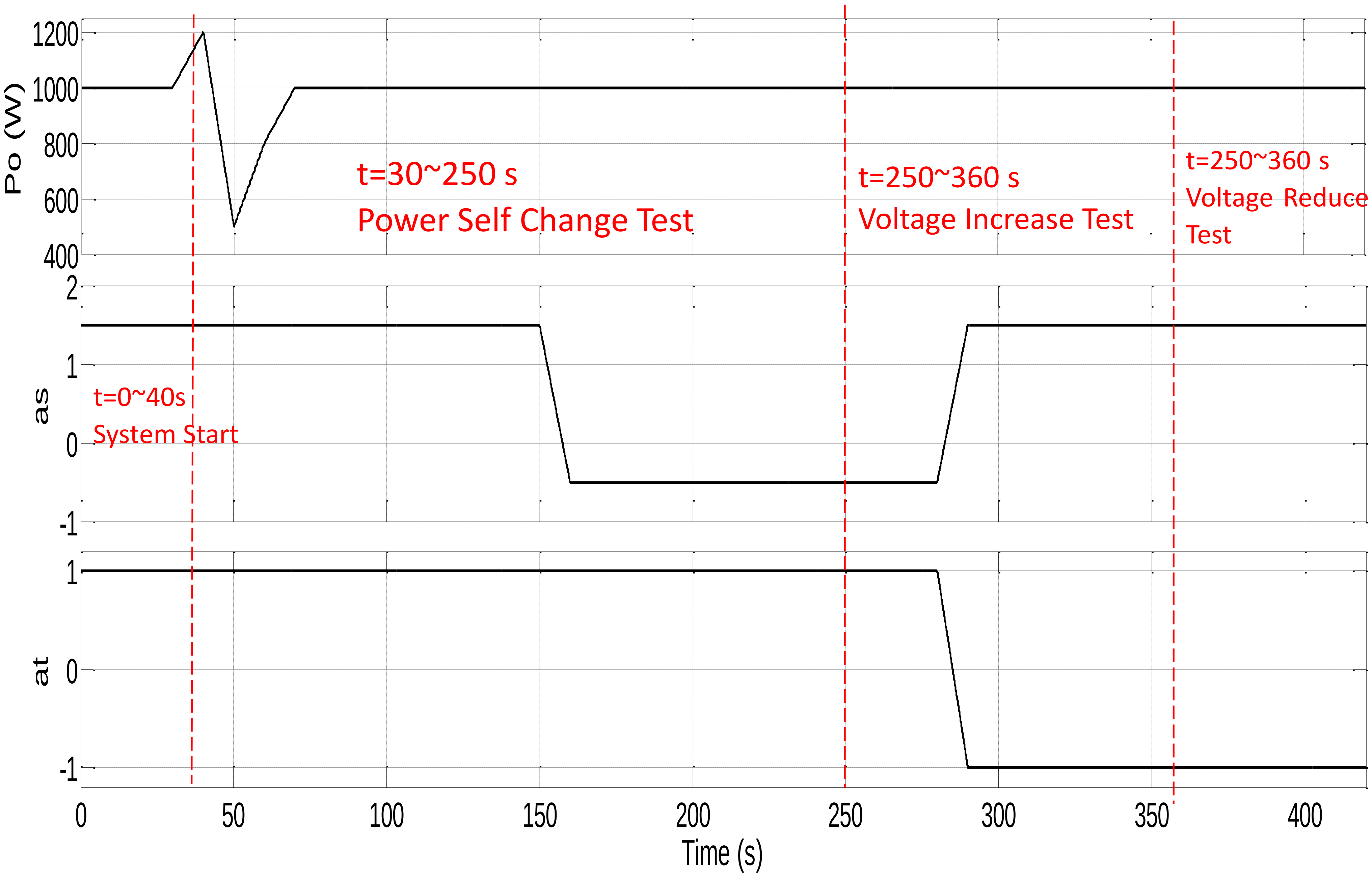
4) Initial Slope Method $P_{s(initial)}$ (if wrong, rest)

5) 36% Method $P_{s(36\%)}$ (if wrong, $P_s = P_{s(initial)}$ otherwise, $P_s = P_{s(36\%)}$)

Voltage Regulation: if VS(P_s)>0; set the voltage to the minimum;
if VS(P_s)<0; set the voltage to the maximum.



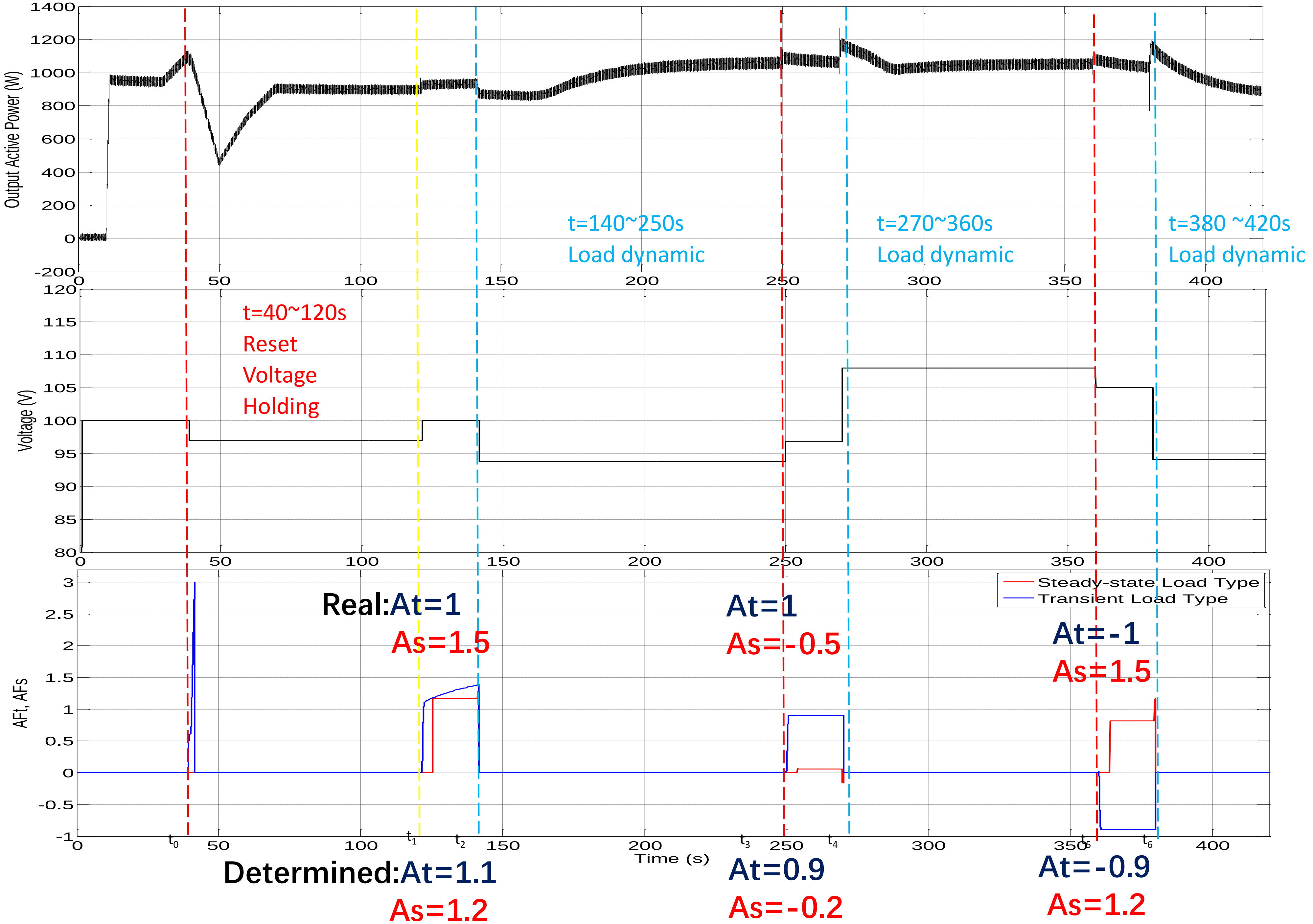
Rectifier
(Load
Emulator)
Resistor
(Transmission
line)
Inverter
(SST)
V_{ELL}
PWM
PWM
OPAL-RT
Power
Control
$P_{ref}\,Q_{ref} = 0$
Dynamic Load
Equation
$P_0, U_0, \alpha_t, \alpha_s, T_p$
Outer Voltage
Inner Current
Decouple
Control
P
V_{ref}
Load
Determine
$\Delta U\%, V_{rated}, Detector\ range$


Po (W)
1200
1000
800
600
400
t=30~250 s
Power Self Change Test
t=250~360 s
Voltage Increase Test
t=250~360 s
Voltage Reduce
Test
as
2
1
0
-1
t=0~40s
System Start
at
1
0
-1
0
50
100
150
200
250
300
350
400
Time (s)

Note:

Transient At is the first point

Static As is the last point



Thanks for your attention!

Any Questions?