SMARTGRID LABORATORY
연세대학교 스마트그리드 연구실

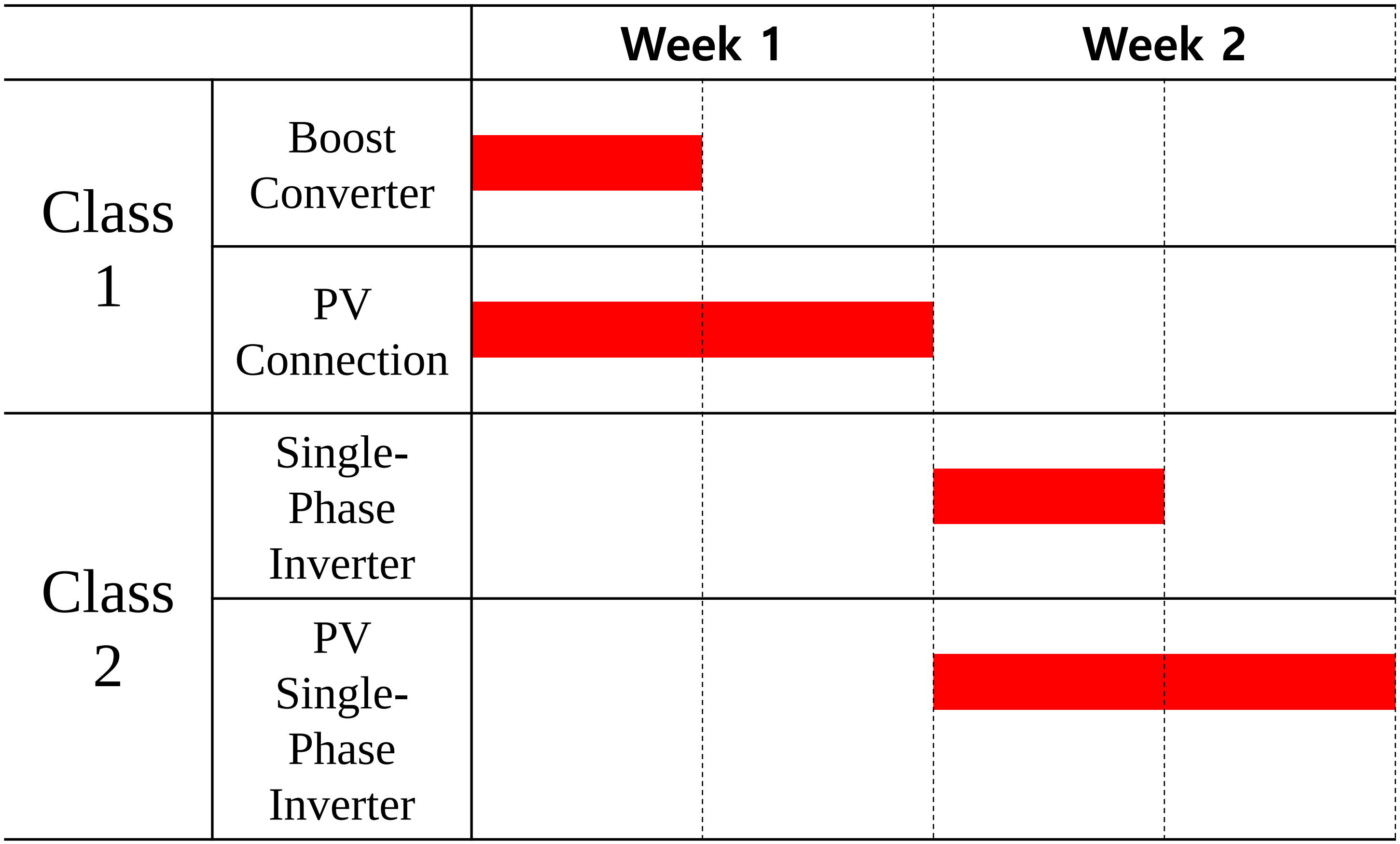
Construction of PV Module using MATLAB-SIMULINK

Power & Control Engineering Experiment

T.A. : Cholmin Kim (Smartgrid Lab)
Contact : calvin16@yonsei.ac.kr

Experiment Milestone

❖ Progress Chart



Preview Requirements

- I-V and P-V curve and operation of PV array
- Concept of Maximum Power Point Tracking (MPPT) of PV
- Duty ratio and operation of boost converter
- Concept of PWM switching control

Experiment Objective

- Learn a basic usage of MATLAB/SIMULINK simulation tool
- Learn a basic concept of boost converter switching operation and duty ratio(D) with PWM control
- Learn a basic concept of duty ratio control with Maximum Power Point Tracking (MPPT) in boost converter connected a PV array

❖ Semiconductor Devices

- **Bipolar Junction Transistor(BJT)**
  - The BJT is a type of transistor that uses both electrons and holes as charge carriers. BJT is controlled by the input base current.

- **Metal-Oxide-Semiconductor Field-Effect Transistor(MOSFET)**
  - MOSFET is a type of field-effect transistor(FET), most commonly fabricated by the controlled oxidation of silicon. MOSFET is controlled by the input gate voltage.

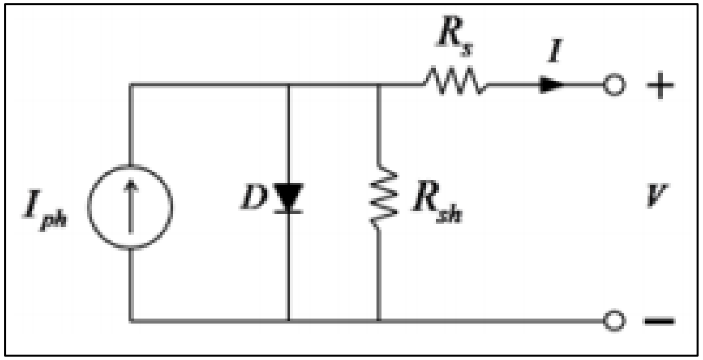
- **Insulated-Gate Bipolar Transistor(IGBT)**
  - IGBT is a three-terminal semiconductor device used as an high efficiency and fast switching.
  - The IGBT combines the simple gate-drive characteristics of MOSFETs with the high-current and low-saturation-voltage capability of BJTs.

Device Characteristic	Power Bipolar	Power MOSFET	IGBT
Voltage Rating	High <1kV	High <1kV	Very High >1kV
Current Rating	High <500A	Low <200A	High >500A
Input Drive	Current, h_{FE} 20-200	Voltage, V_{GS} 3-10V	Voltage, V_{GE} 4-8V
Input Impedance	Low	High	High
Output Impedance	Low	Medium	Low
Switching Speed	Slow (uS)	Fast (nS)	Medium
Cost	Low	Medium	High

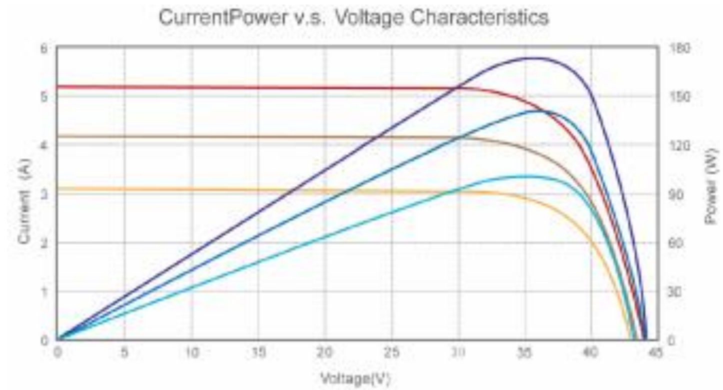
<Comparison Table>

❖ Photovoltaic System

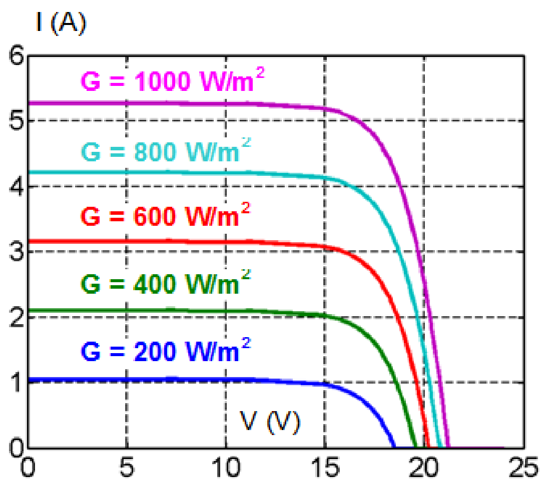
▪ Solar Cell



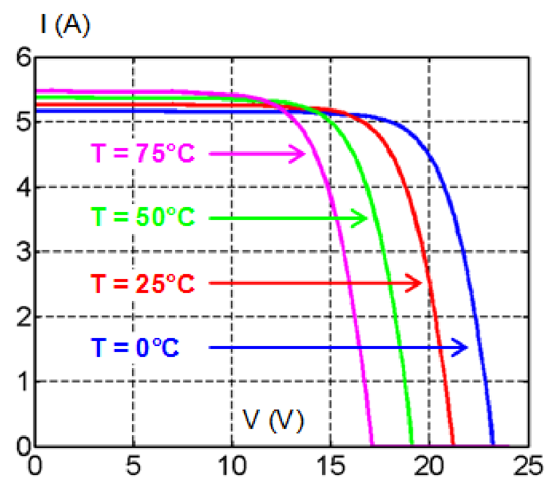
< PV Cell circuit model>



<PV I-V & P-V Curve>

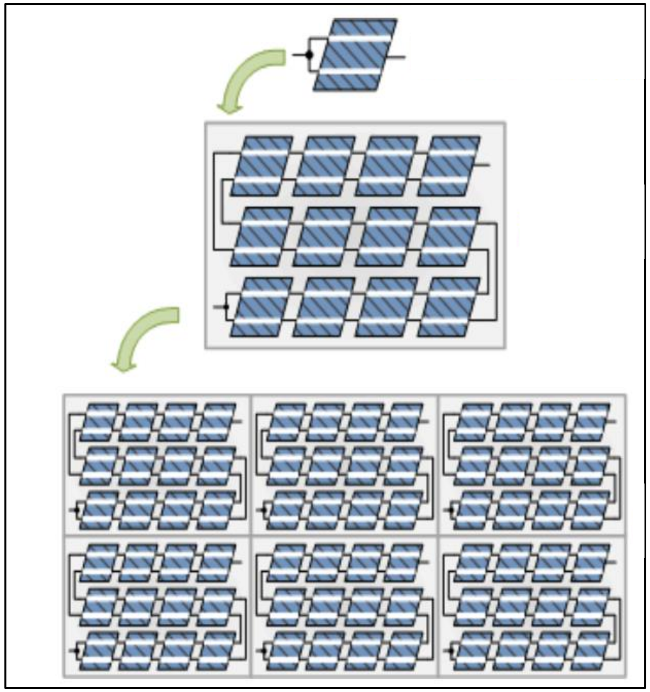


< PV Power vs Irradiance>

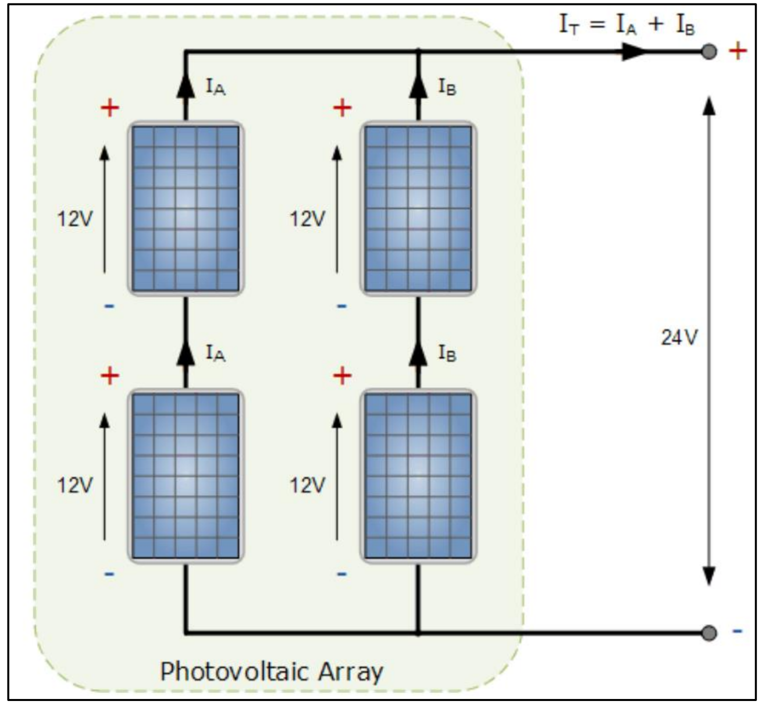


< PV Power vs Temperature>

❖ PV Array



(a) PV cell → PV panel → PV array



(b) Example of PV array

- Picture (a) shows PV Cell connection changes in to PV panel and connection of PV panel changes in to PV array.
- Picture (b) shows connection of PV panel. Two series circuit of PV panel is connected parallel. So the output voltage will be 24 V and total current equals to 7.5 A (assume that PV panel produces 3.75 A at full sun). Maximum power of PV array would be 180 W.

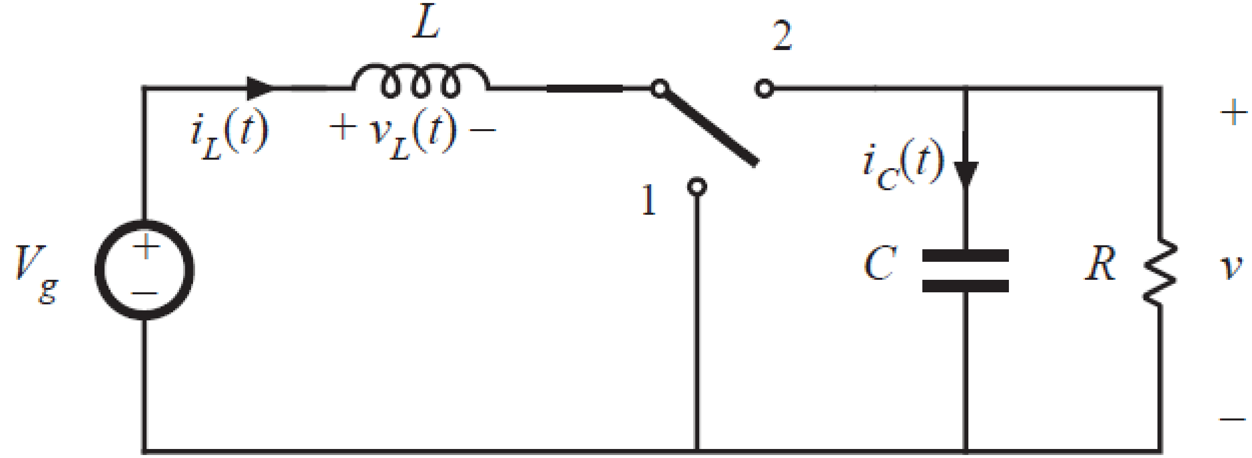
❖ Boost Converter

▪ Definition

- Boost Converter is a switched-mode converter that is capable of producing an output voltage greater in magnitude than the input voltage (Step-up Converter)

▪ Description

- Switching position 1→2→1 occurs during one cycle
- Duty ratio(D) is the ratio of time when the switch is in position 1.
- D modulation range is between 0 and 1



❖ Boost Converter

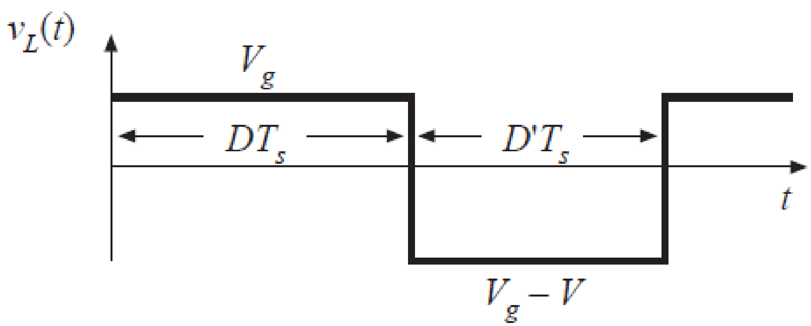
- During one cycle, the equation below is obtained

$$\underbrace{(V_g)DT_s}_{\text{position 1}} + \underbrace{\left(V_g - V\right)(1-D)T_s}_{\text{position 2}} = 0$$

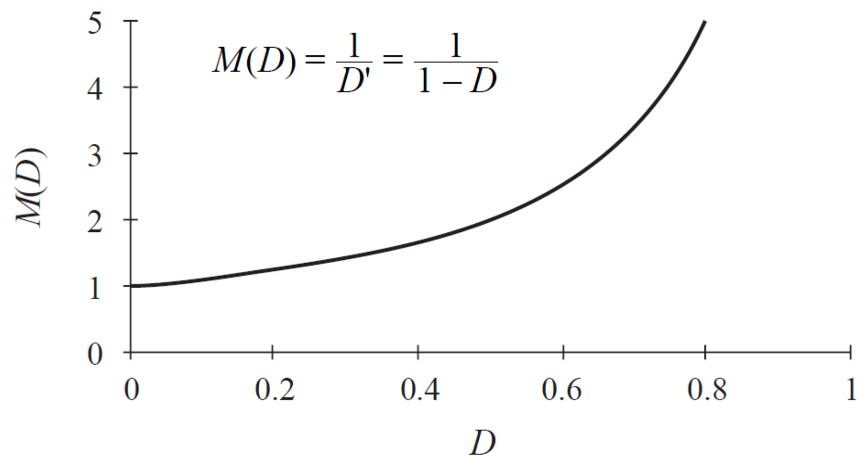
- Output voltage is then

$$V_o = \frac{V_g}{1-D}$$

- As seen from the voltage conversion ratio(M(D)), larger the duty ratio, larger the output voltage



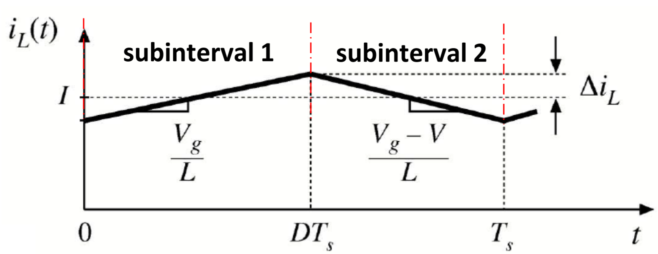
<Switching cycle>



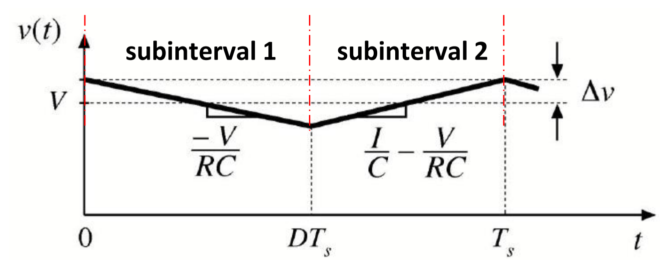
<Voltage conversion ratio>

❖ Determination of Δi_L and Δv_C

- Inductor Current Ripple
  - Inductor current slope during subinterval 1:
    $\frac{di_L(t)}{dt} = \frac{v_L(t)}{L} = \frac{V_g}{L}$
  - Inductor current slope during subinterval 2:
    $\frac{di_L(t)}{dt} = \frac{v_L(t)}{L} = \frac{V_g - V_o}{L}$
    $2\Delta i_L(\mathit{Change\ in\ inductor\ current}) = \frac{V_g}{L} DT_s$
  - Solve for peak ripple:
    $\Delta i_L = \frac{V_g}{2L} DT_s$



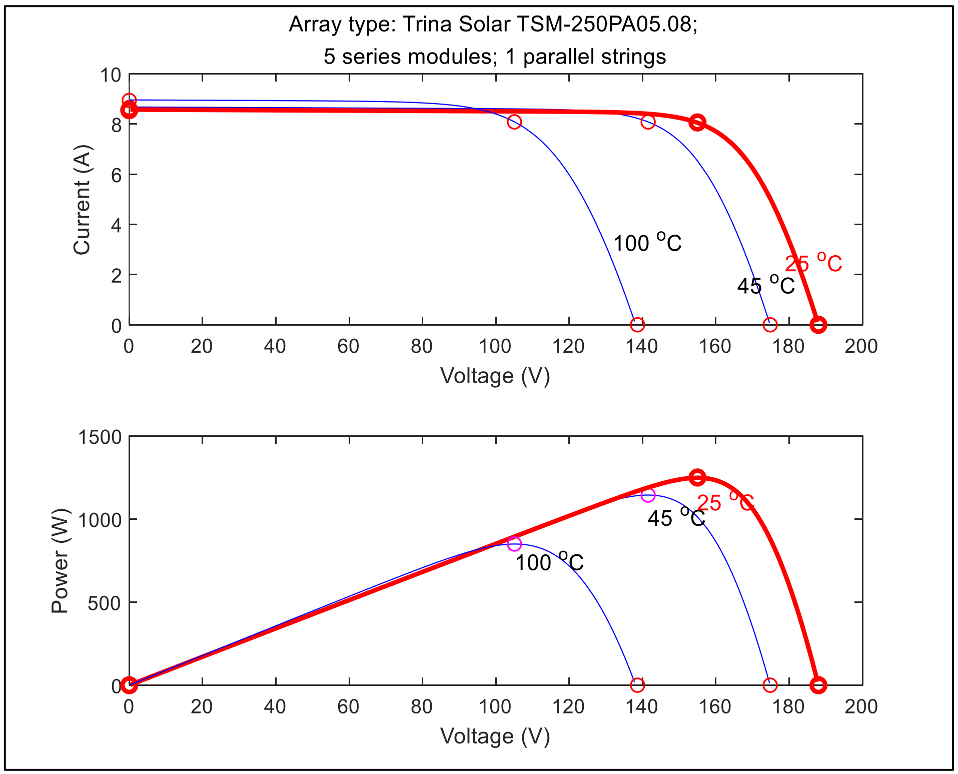
- Capacitor Voltage Ripple
  - Capacitor voltage slope during subinterval 1:
    $\frac{dv_C(t)}{dt} = \frac{i_C(t)}{C} = \frac{-V_o}{RC}$
  - Capacitor voltage slope during subinterval 2:
    $\frac{dv_C(t)}{dt} = \frac{i_C(t)}{C} = \frac{I}{C} - \frac{V_o}{RC}$
    $-2\Delta v_c(\mathit{Change\ in\ capacitor\ voltage}) = \frac{-V_o}{RC} DT_s$
  - Solve for peak ripple:
    $\Delta v_c = \frac{V_o}{2RC} DT_s$

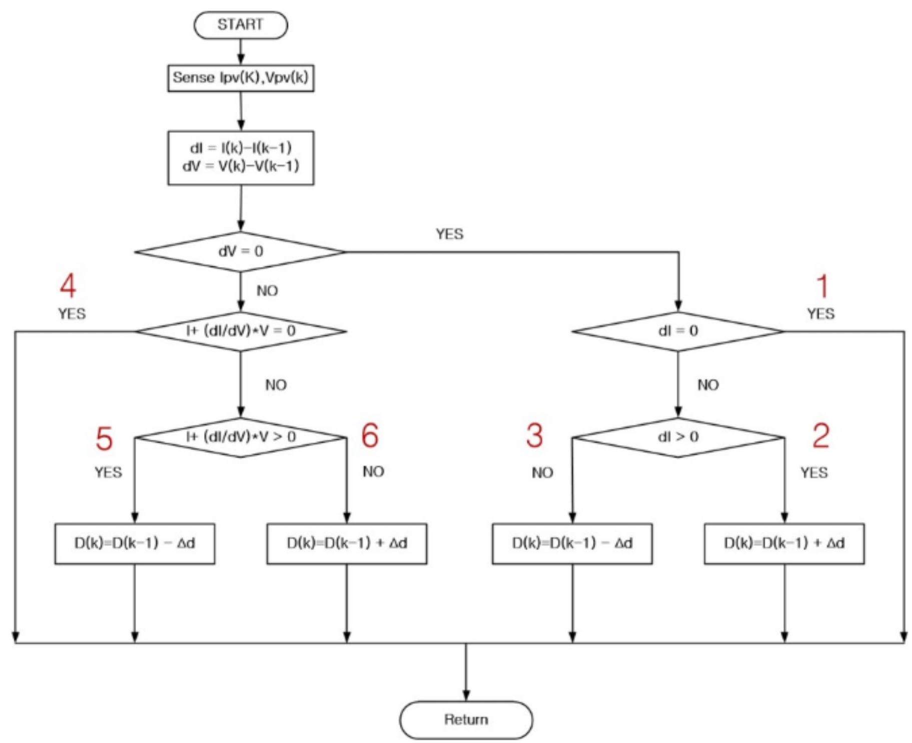


Maximum Power Point Tracking (MPPT)

❖ What is MPPT

- System to maximize the output in any condition
- There are techniques to find the maximum power point
  (Perturb and Observe, **Incremental Conductance**, Constant Voltage, Current Sweep)
- Incremental Conductance algorithm predicts the effect of voltage change with PV array current and voltage changes.

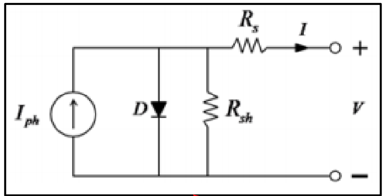


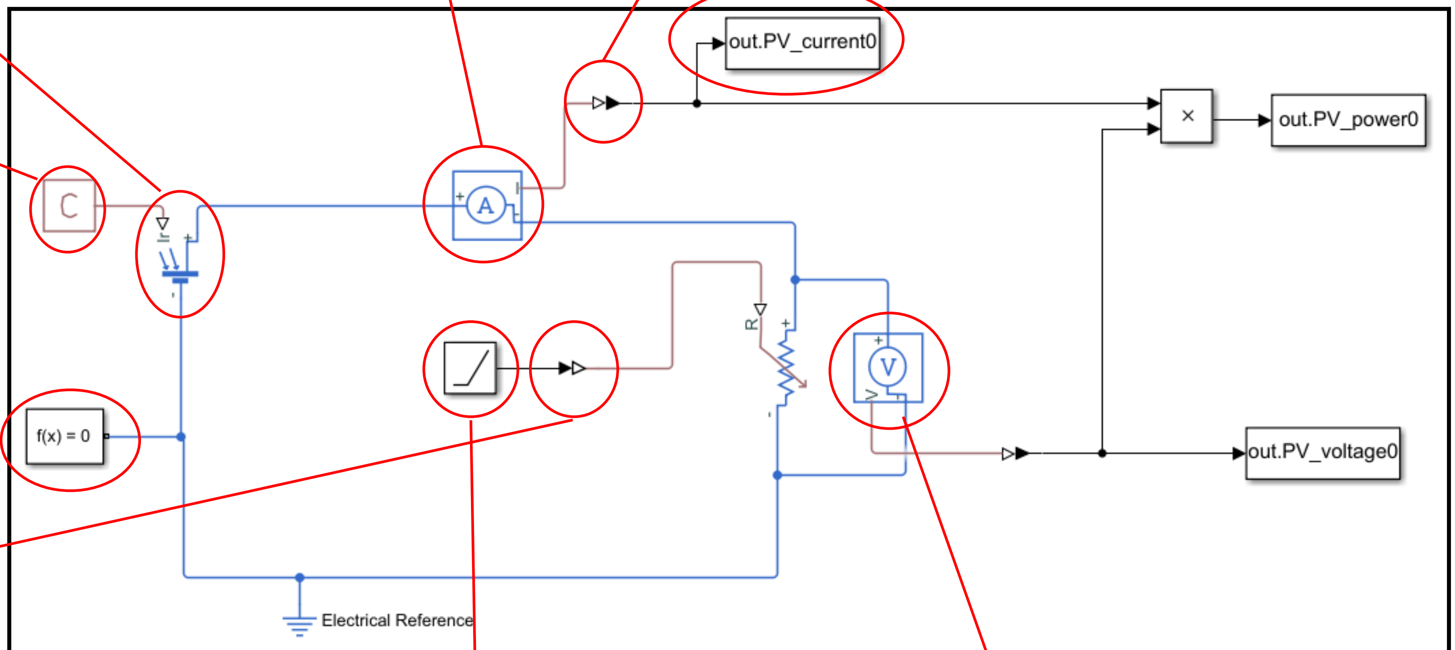


PV Generator Simulation

PV Cell & Array

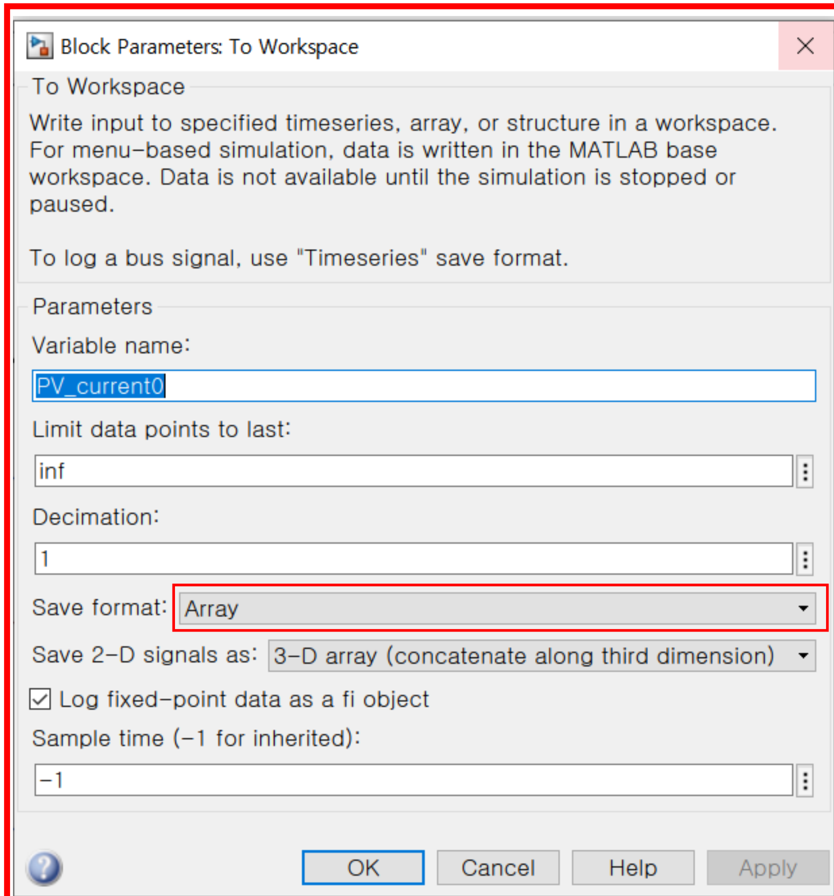
❖ PV Cell Circuit





< Output voltage & current measurement in variable resistor>

❖ PV Cell Circuit




```
figure(1)
plot(out.PV_voltage0,out.PV_power0)
xlabel('PV Voltage(V)')
ylabel('PV Power(W)')
title('PV P-V Characteristic Curve')

figure(2)
plot(out.PV_voltage0,out.PV_current0)
xlabel('PV Voltage(V)')
ylabel('PV Current(A)')
title('PV I-V Characteristic Curve')
```

- This code must be written on the Matlab Workspace

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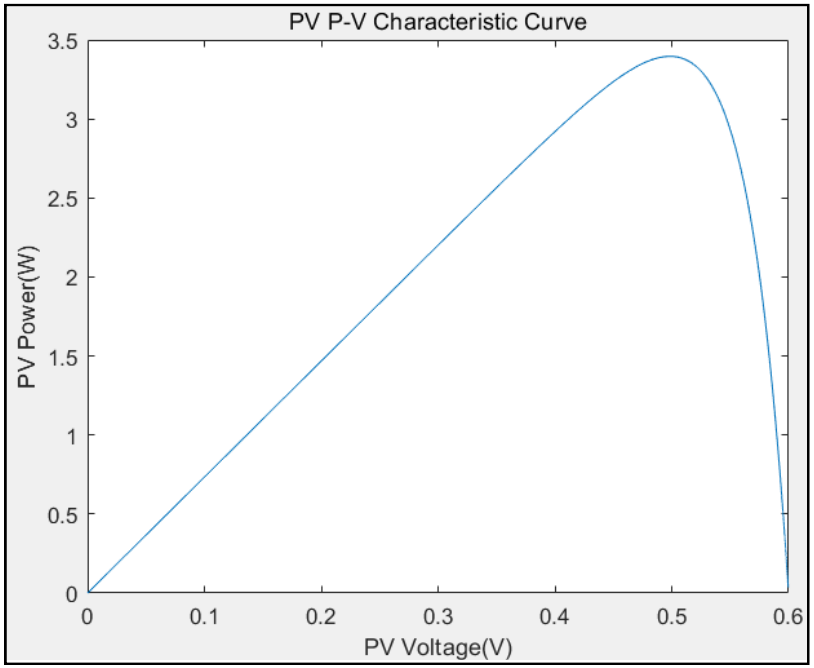
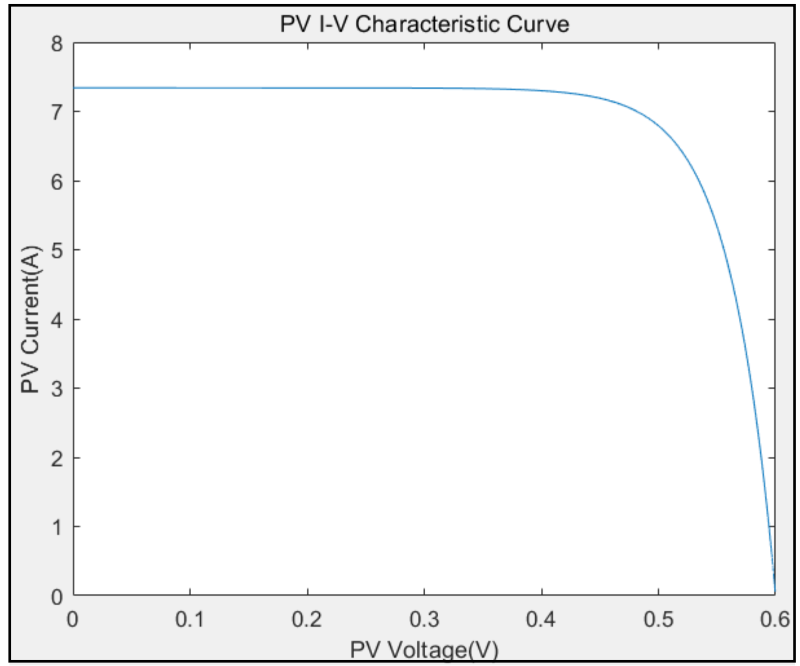
❖ Simulation Result

P-V Curve

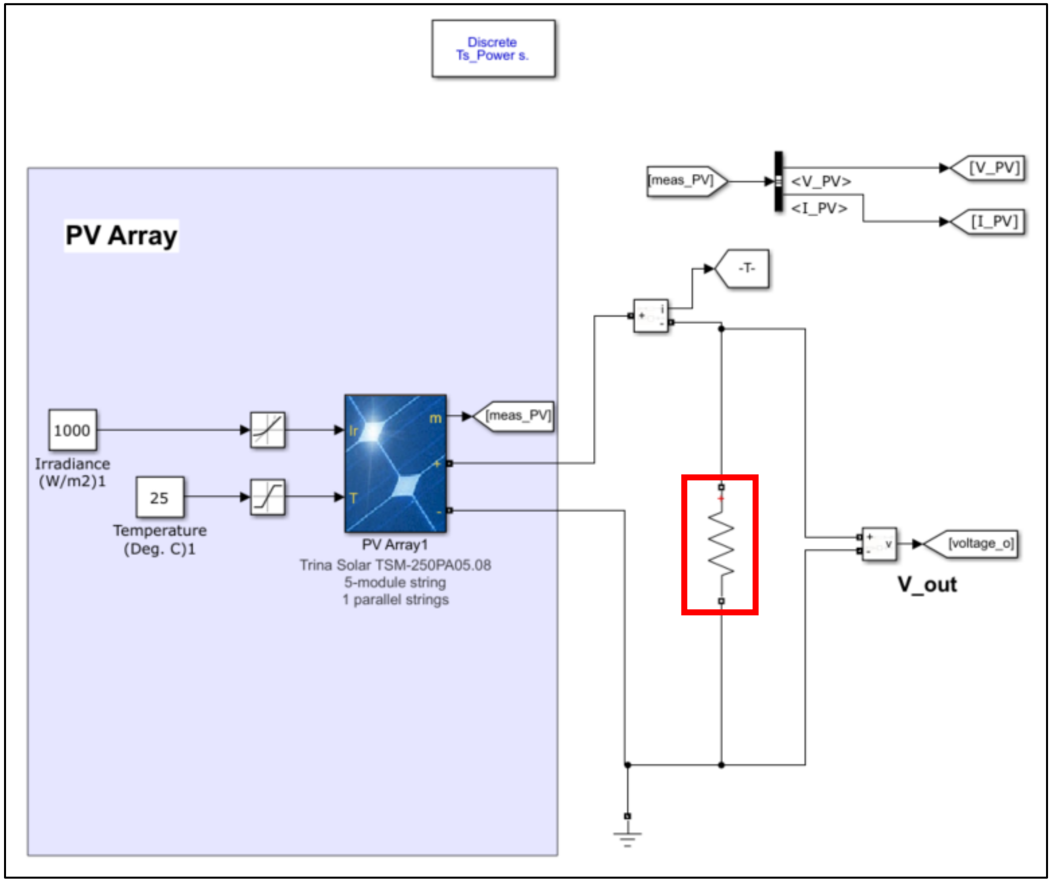


I-V Curve



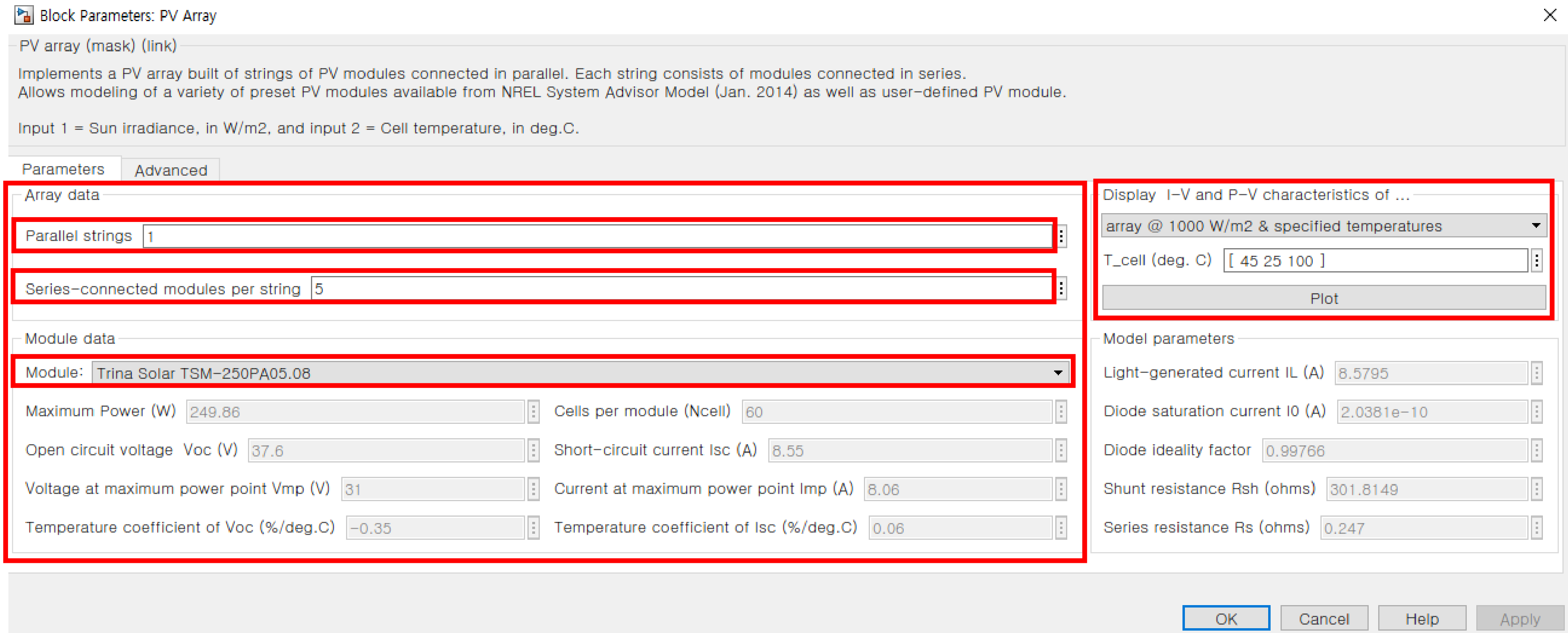
- Draw the plots of the P-V Curve & I-V Curve.

❖ PV Array Circuit



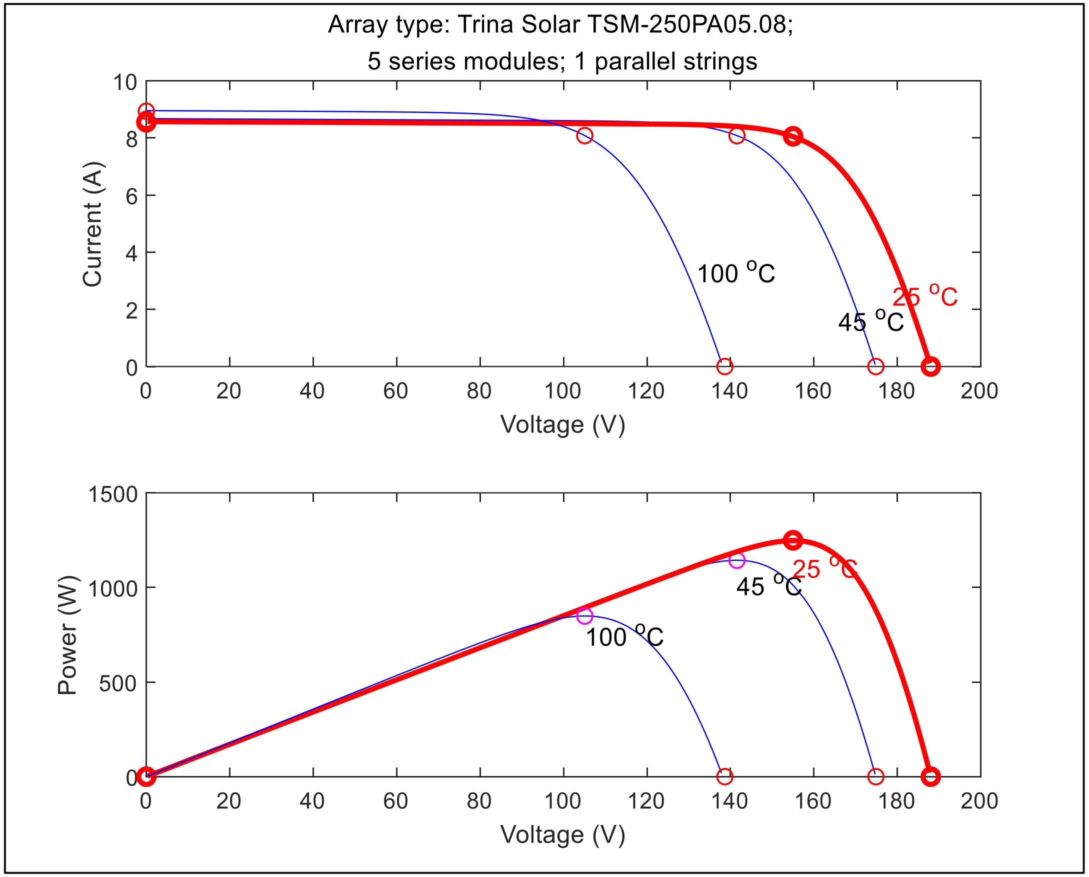
- Connect a parallel resistor to PV array.

❖ Maximum Power Operating Point



- Check I-V & P-V Curve of PV array.
- Changing module data and the array data yields waveforms of different voltage ranges.

❖ Maximum Power Operating Point (MPOP)



- Derive basic PV generating power at 1000W/m2 and 25 deg.
- This plot implies a MPOP and voltage operation range.

Discussion (PV Array)

- Change the resistance, check the output voltage and current and draw the PV V-I curve.
  (Temperature = 25℃)

Resistance (Ω)	Voltage (V)	Current (A)

Discussion (PV Array)

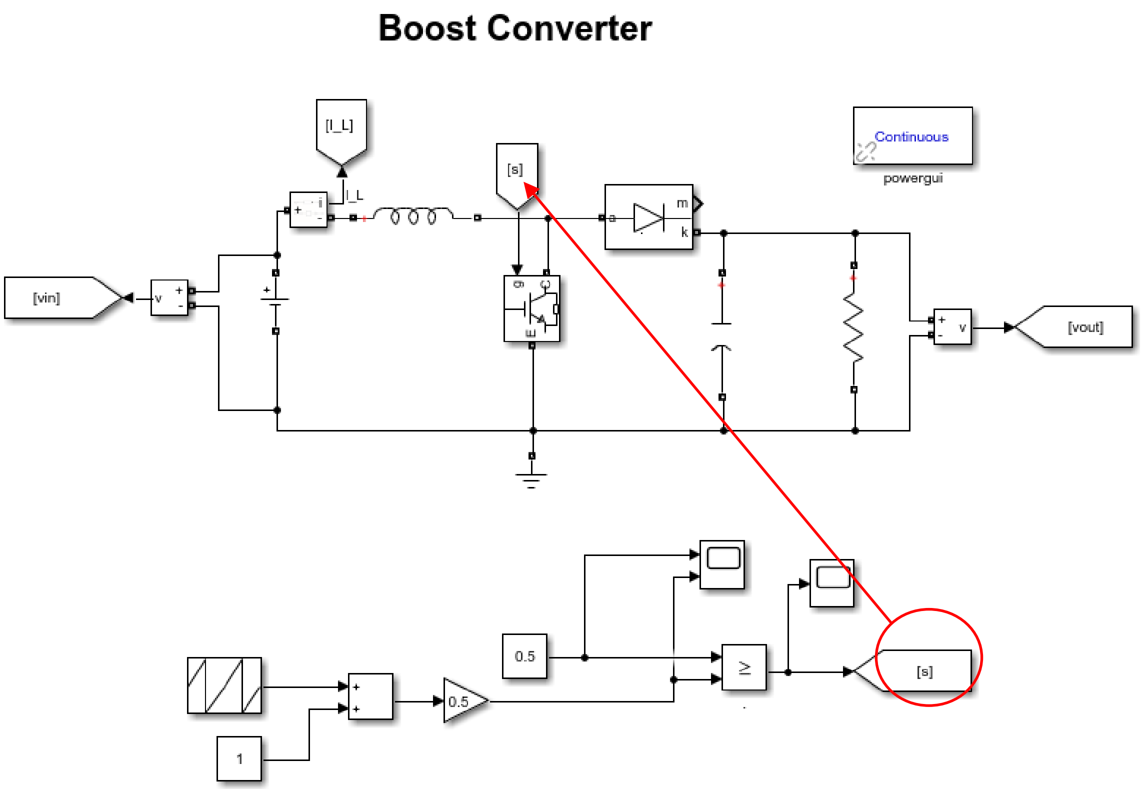
- Change the resistance, figure out the MPOP.
  (Temperature = 25℃)

Resistance (Ω)	Voltage (V)	Current (A)

PV Generator Simulation

Boost Converter

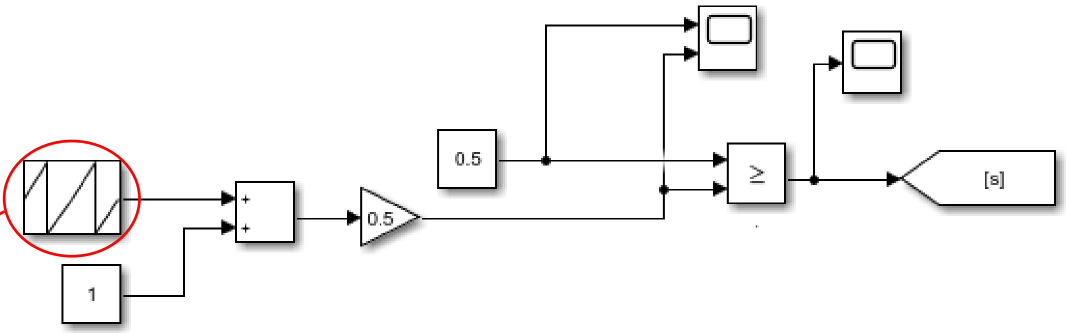
❖ Boost Converter Circuit

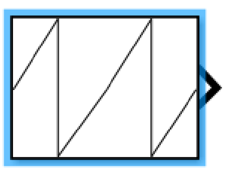


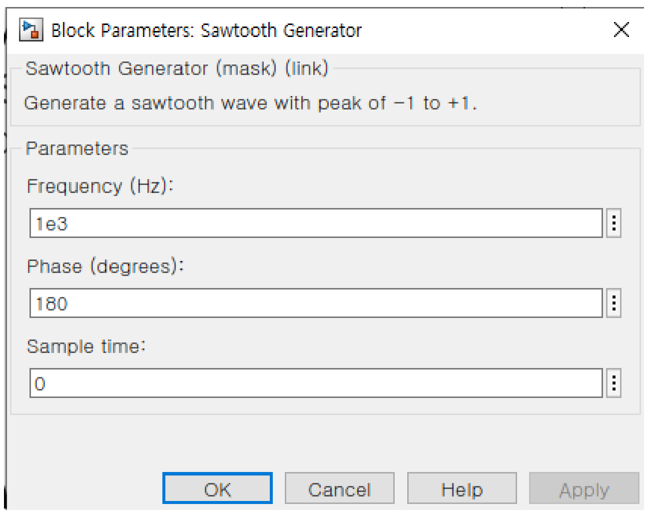
- When the Boost Converter is connected to the ideal voltage source, the output voltage can be boosted according to the duty ratio (D).
- Figure out the duty ratio in the right side. D=??

Boost Converter connected PV Array

❖ Switching signal






Block Parameters: Sawtooth Generator

Sawtooth Generator (mask) (link)

Generate a sawtooth wave with peak of −1 to +1.

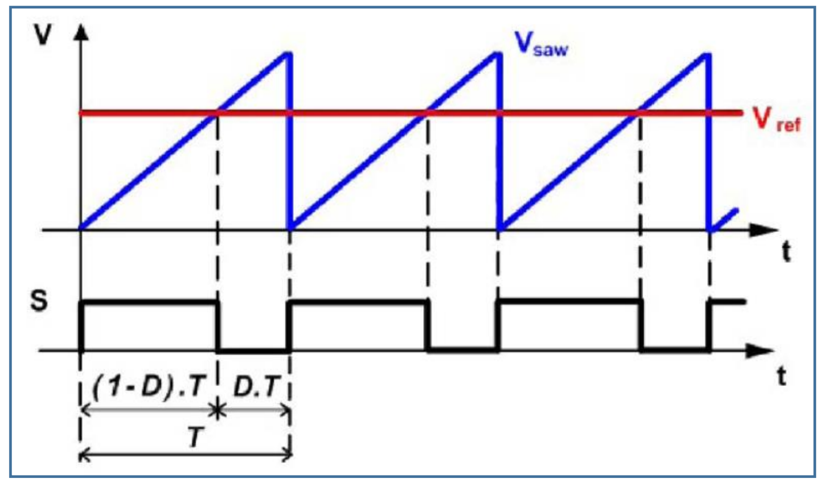
Parameters

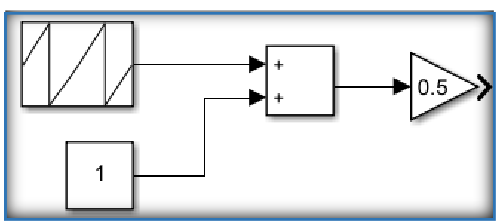
Frequency (Hz):
1e3

Phase (degrees):
180

Sample time:
0

OK | Cancel | Help | Apply





Provide offset in order to make sawtooth change between 0 and 1

❖ Specification of System Circuit Component (Boost Converter)

Parameter	Given Value
Input Voltage	100 V
On/Off Switch	IGBT/Diode
Capacitance (C)	5000 μF
Inductance (L)	80 mH
Resistance (R)	5 Ω

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❖ Simulation Result

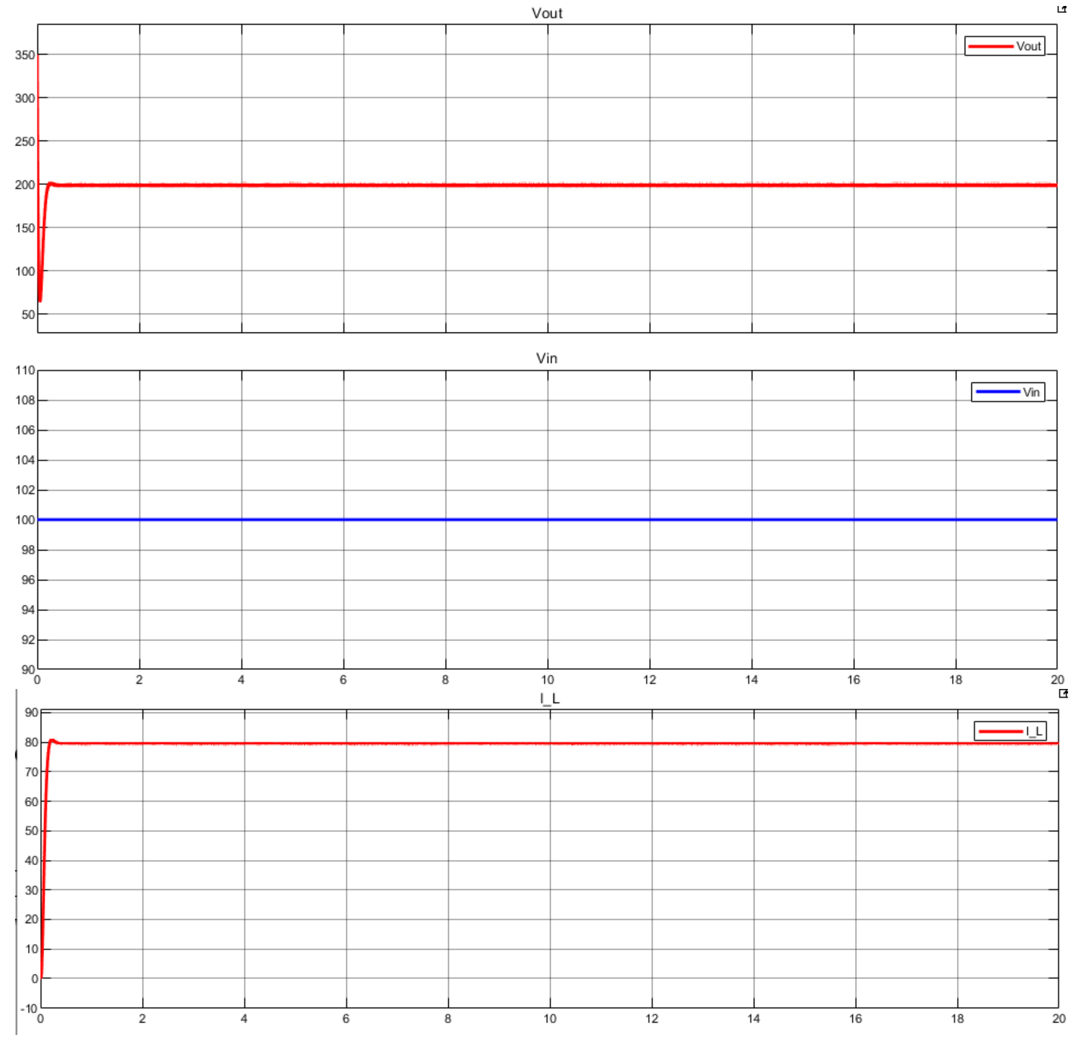
Output Voltage

D = 0.5

$V_{out} = 2 \times V_{in}$

Input Voltage

Inductor current



Discussion (Boost Converter)

- Plot the output voltage ripple & inductor current and figure out the magnitude of ripple with changing the capacitance

Capacitance (C)	Voltage Ripple	Current Ripple

Discussion (Boost Converter)

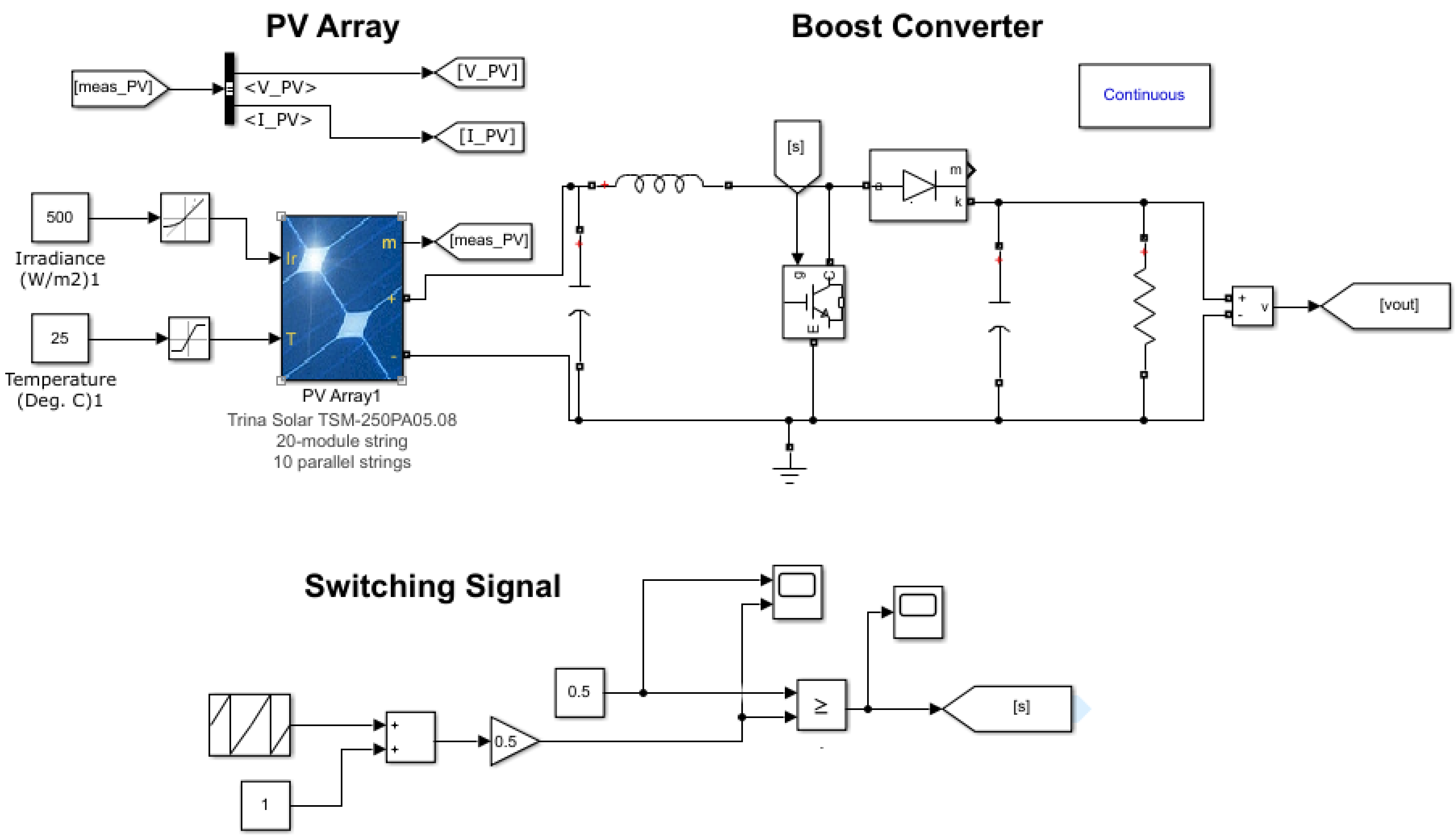
- Plot the output voltage ripple & inductor current and figure out the magnitude of ripple with changing the inductance

Inductance (L)	Voltage Ripple	Current Ripple

PV Generator Simulation

PV Array &
Boost Converter Design

❖ PV Array and Boost Converter System Circuit



❖ Specification of System Circuit Components (PV Array & Boost Converter)

Parameter	Given Value
Irradiance	500 W/m^2
Temperature	25 Deg.
PV Module data	Trina Solar TSM-250PA05.08
PV Parallel strings	10 parallel strings
PV Series connected modules per string	20 module string
PV side Capacitance (C)	1000 μF
Output side Capacitance (C)	5000 μF
Inductance (L)	80 mH

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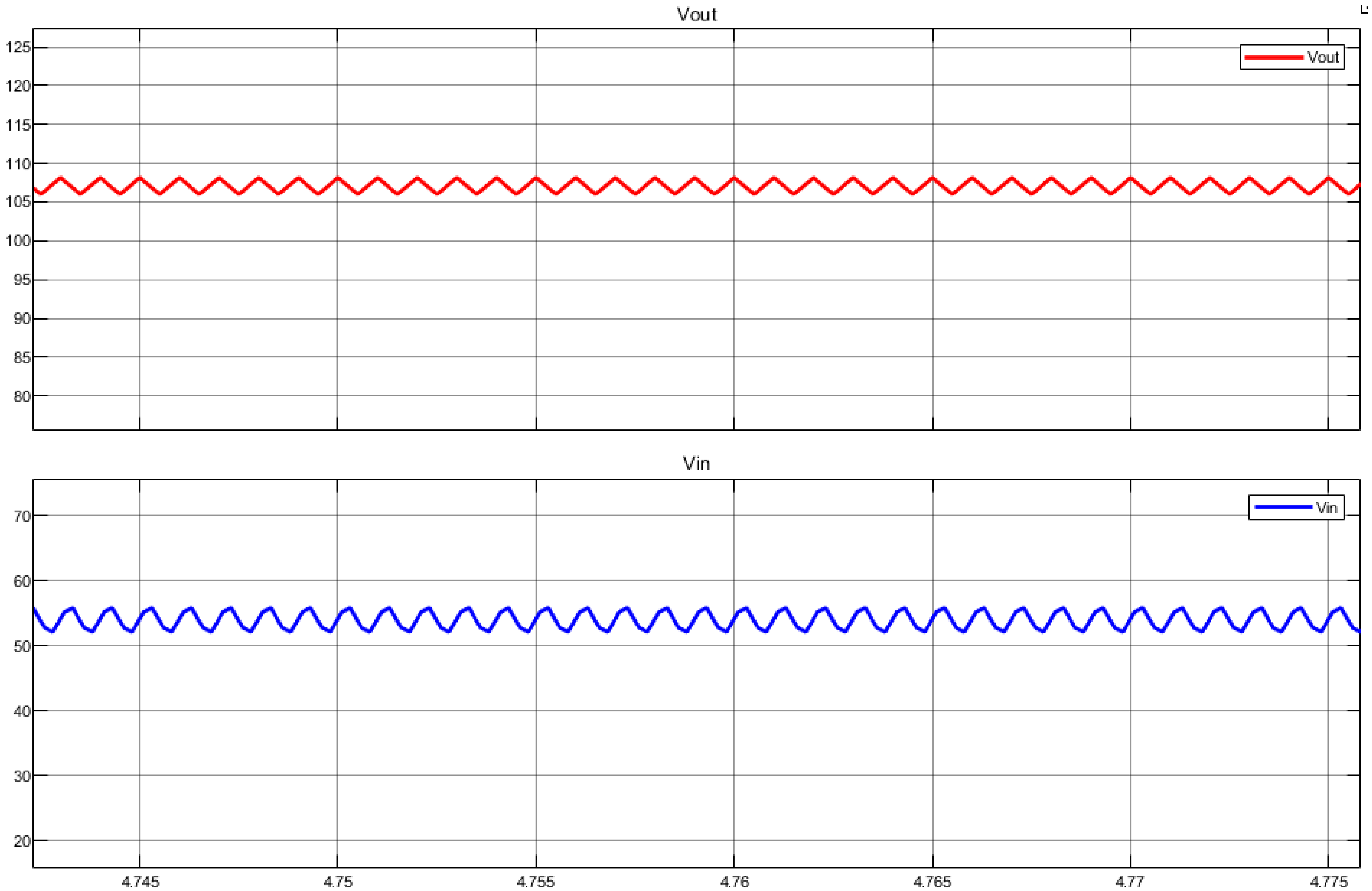
❖ Simulation Result



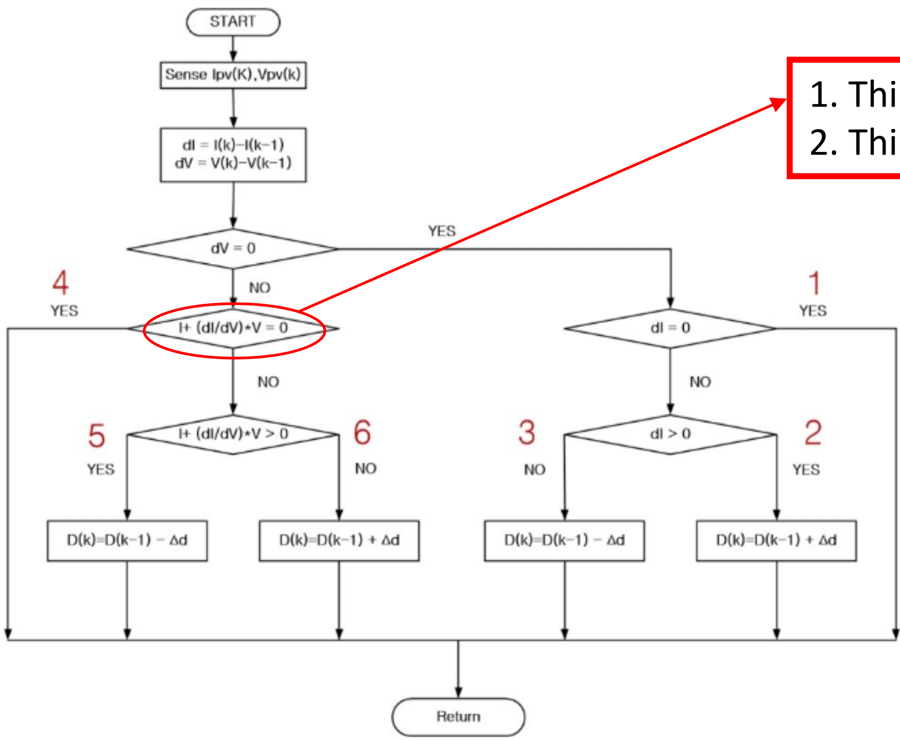
- Output voltage is doubled. Why?

- Change duty ratio (D) of Boost converter and check the output voltage variation.

Duty Ratio (D)	Input voltage (V)	Output voltage (V)

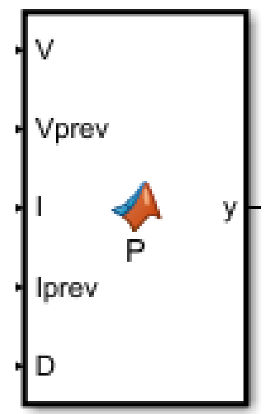
❖ Using MPPT Controller

- Incremental Conductance Technique to find the maximum power point



1. Think about the equation P = VI
2. Think about the P-V curve

Matlab Function Block



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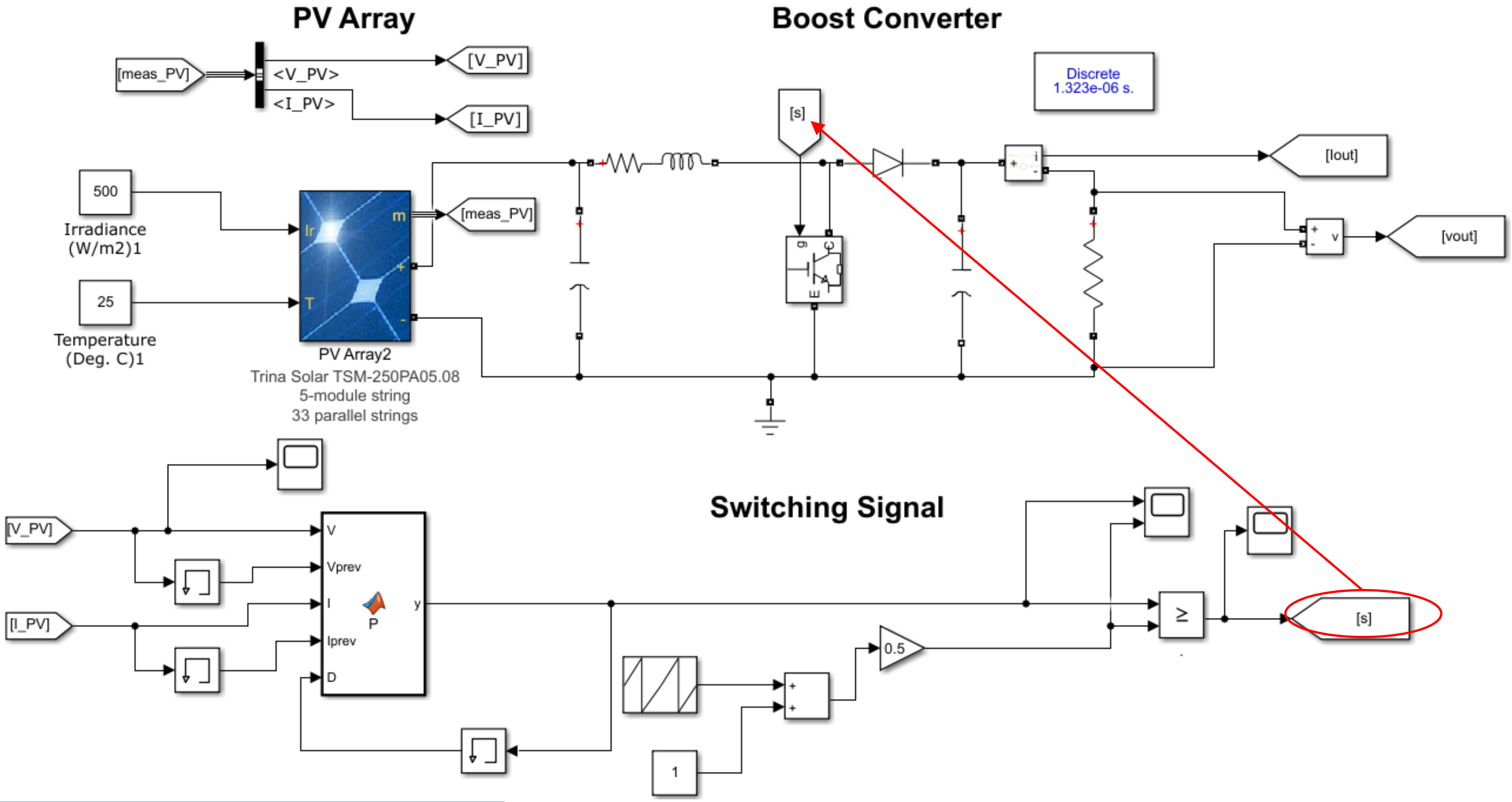
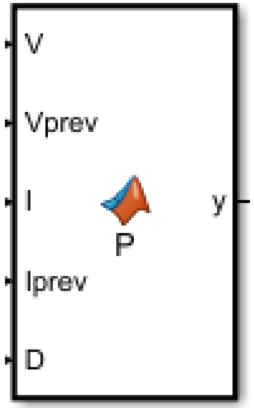
❖ PV+Boost+MPPT Controller circuit



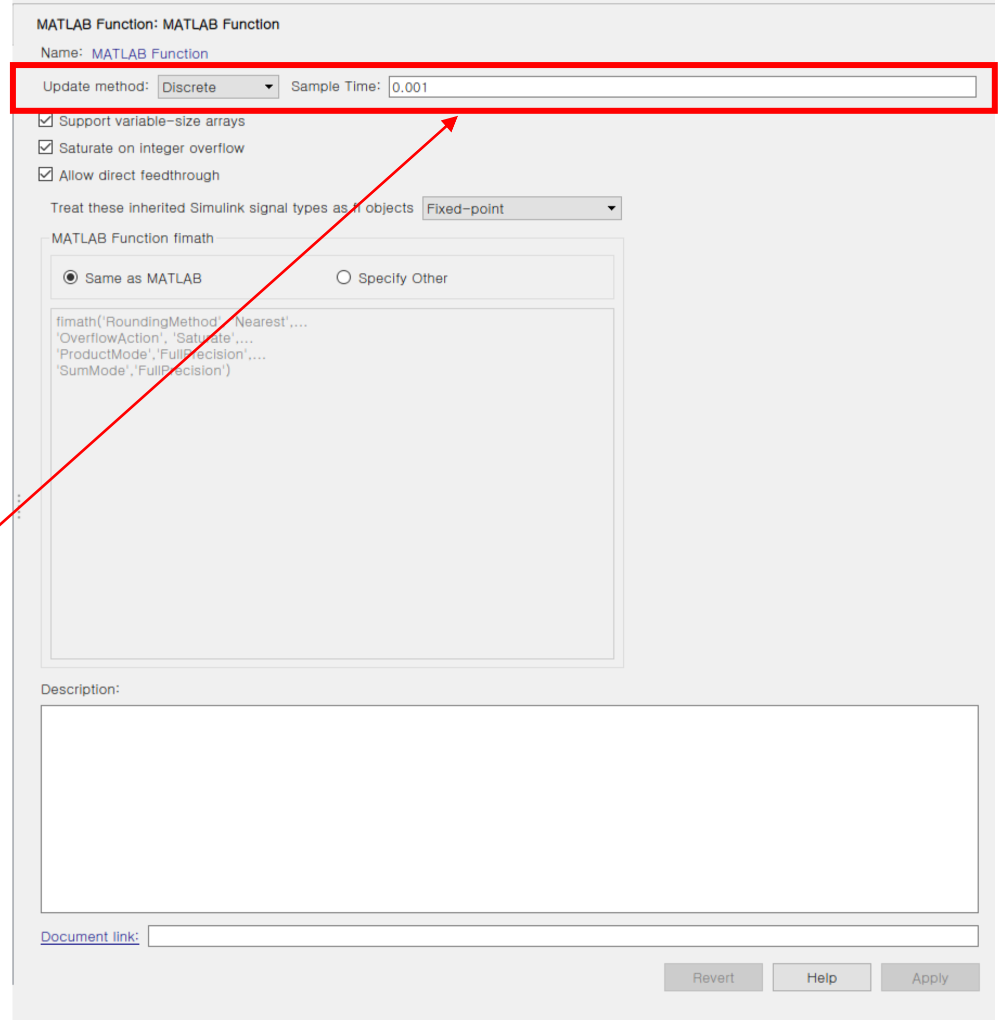

```
Ts_Power = 1.322751322751323e-06 ;
Ts_Control = 2.645502645502646e-05 ;
```

Time step (write in matlab)

❖ MPPT Controller



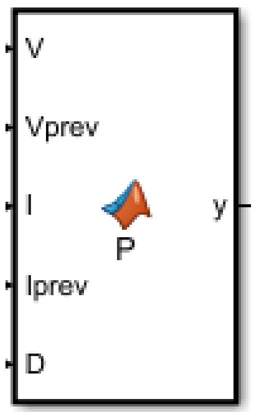
① Right click
② explore



Sample Time should be same as switching frequency!

Discussion (Boost Converter + PV)

- Write the code
  (Check the algorithm p.33)

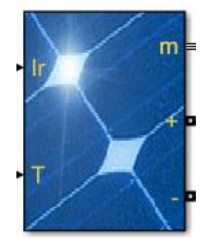


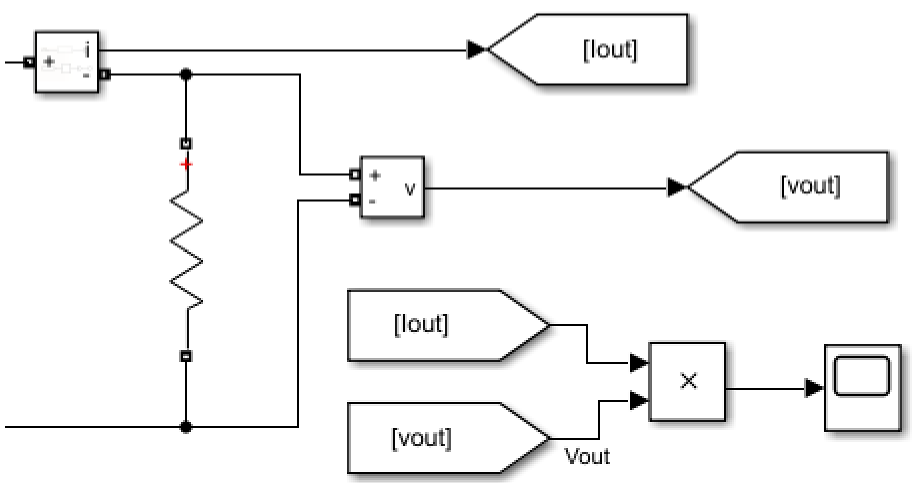

```
function y = P(V, Vprev, I, Iprev,D)

end
```

Discussion (Boost Converter + PV)

- Plot the duty ratio and input/output voltage of the converter
- Check the output power of the PV array and compare with the output power of the converter.





compare