






PSCAD

Renewable Integration - Modeling and Details

Lalin Kothalawala MSc. PEng.
pscad.com

Presented by: Lalin Kothalawala

Manitoba HYDRO INTERNATIONAL

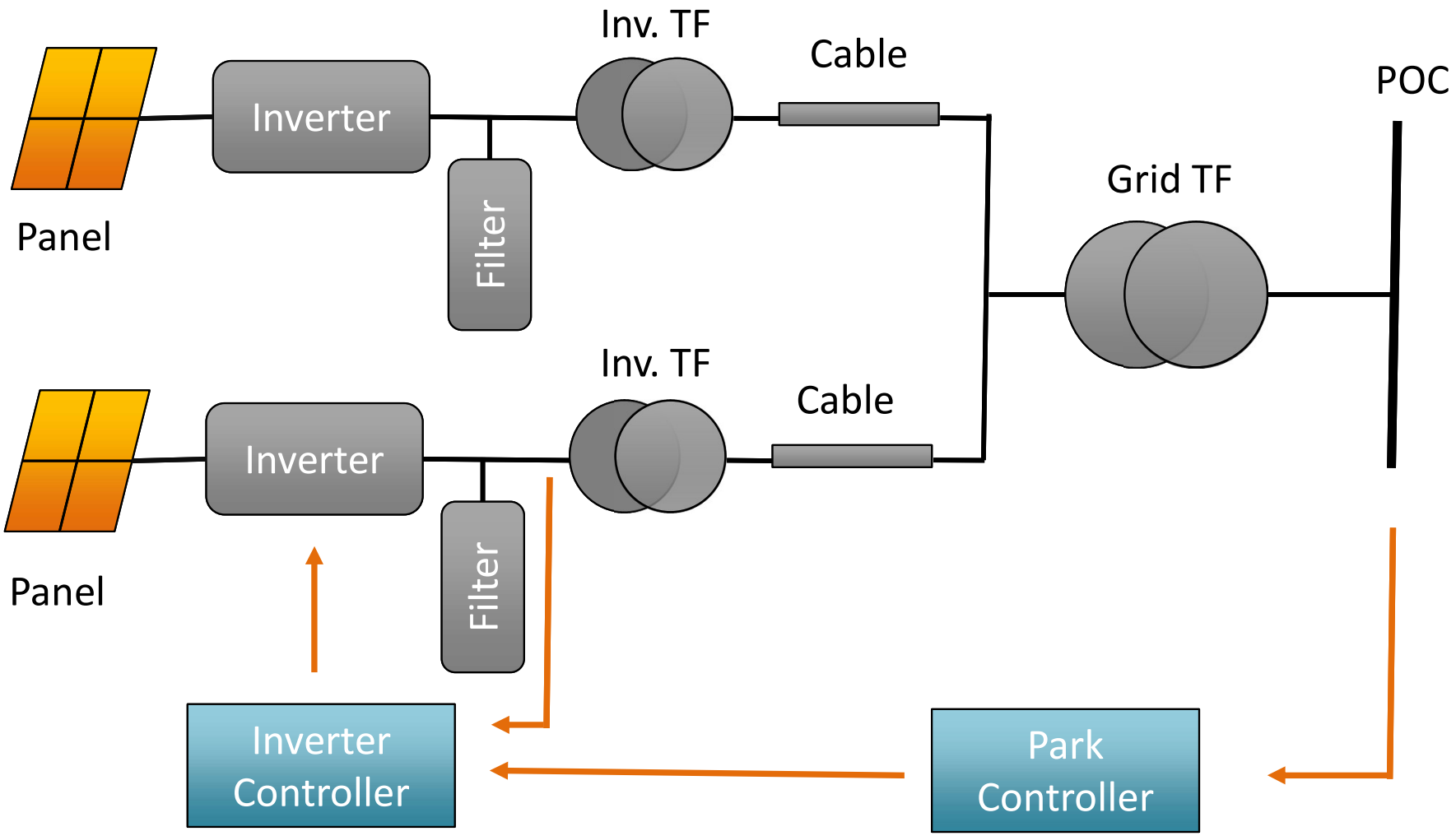
Solar PV Example

Overall System Composition

- PV panel
- DC/DC converter
- Inverter
- Inverter controller
- Filter
- Inverter transformer
- Cable system
- Grid transformer
- Point of Connection (POC)
- Park controller

Solar PV Example

Overall Schematic



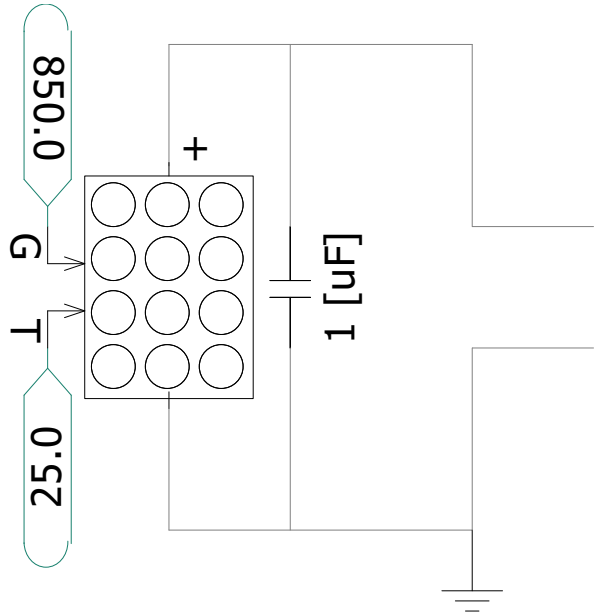
Representing the Solar Plant

Model Details

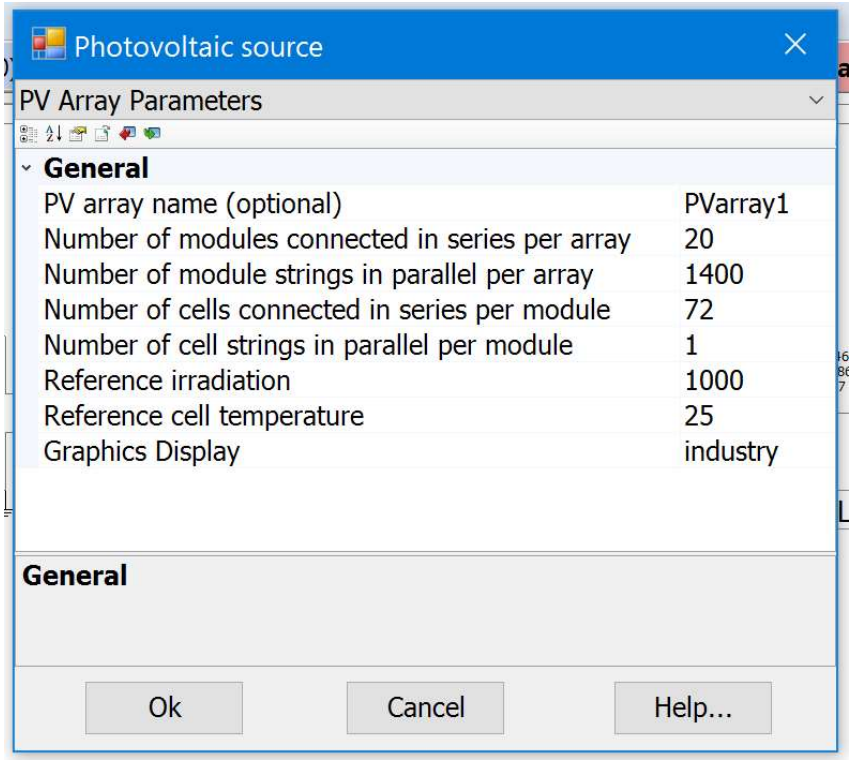
- PV panel
- DC/DC converter
- Inverter
- Inverter controller
- Filter
- Inverter transformer
- Cable system
- Grid transformer
- Point of Connection (POC)
- Park controller

Solar Farm - Simulation

- PV Panel

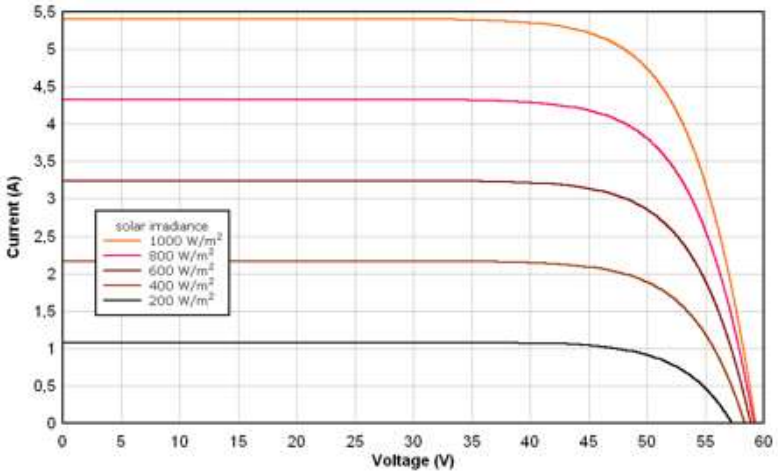


PV panel model

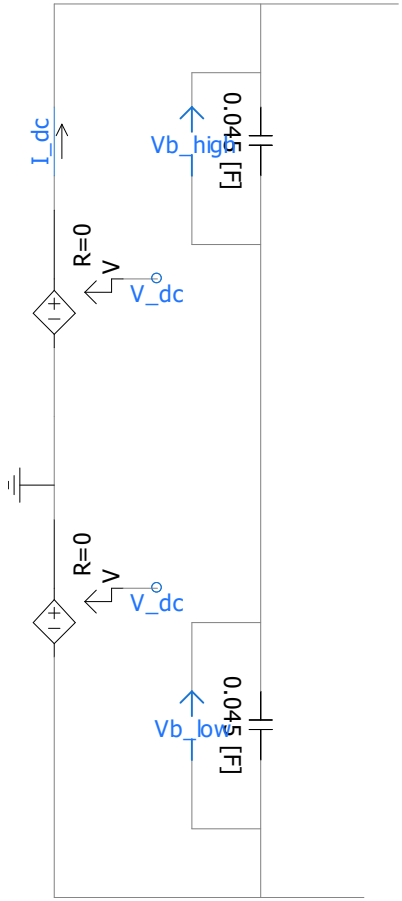


Solar Farm - Simulation

- PV Panel



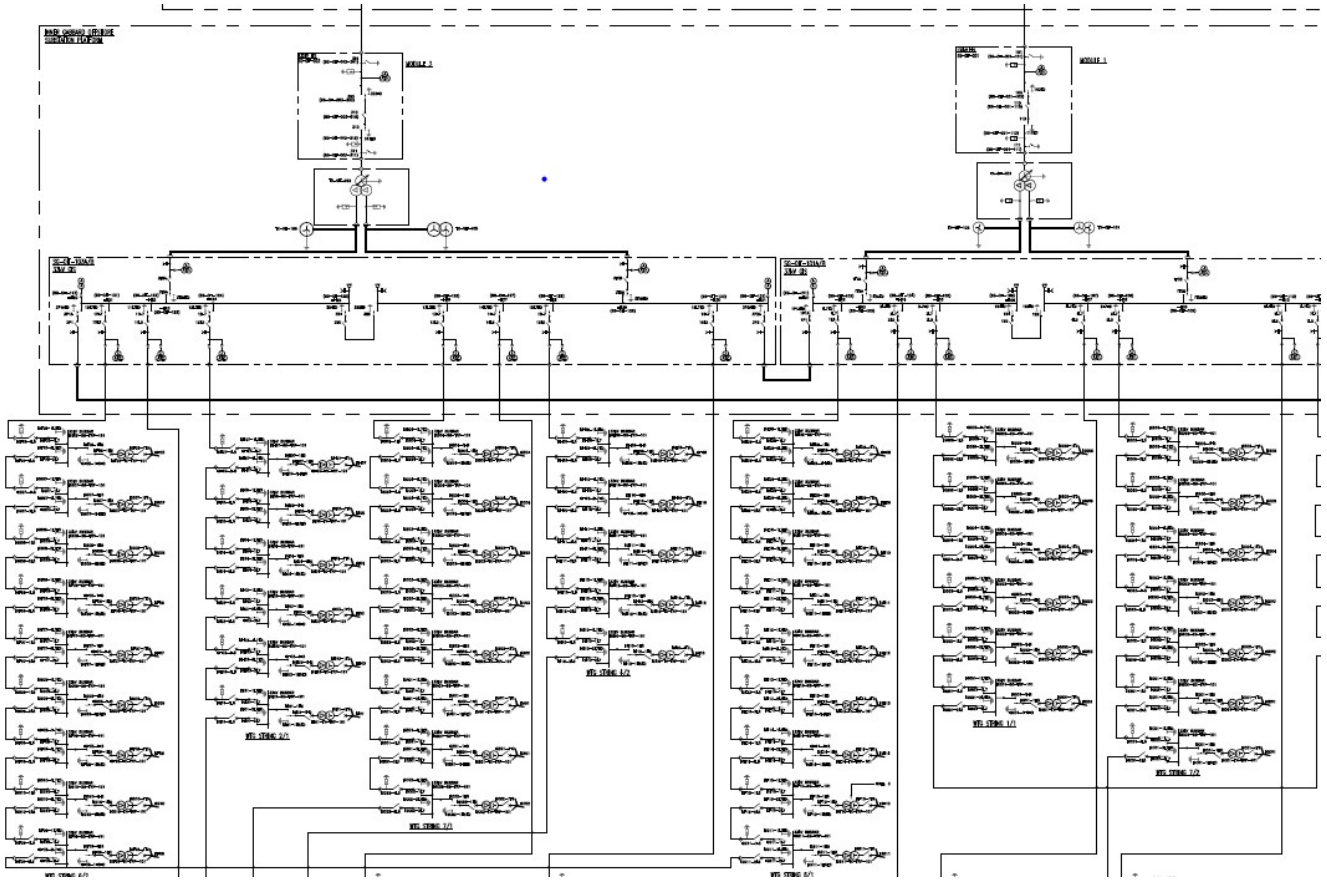
Vdc



Equivalent DC source model

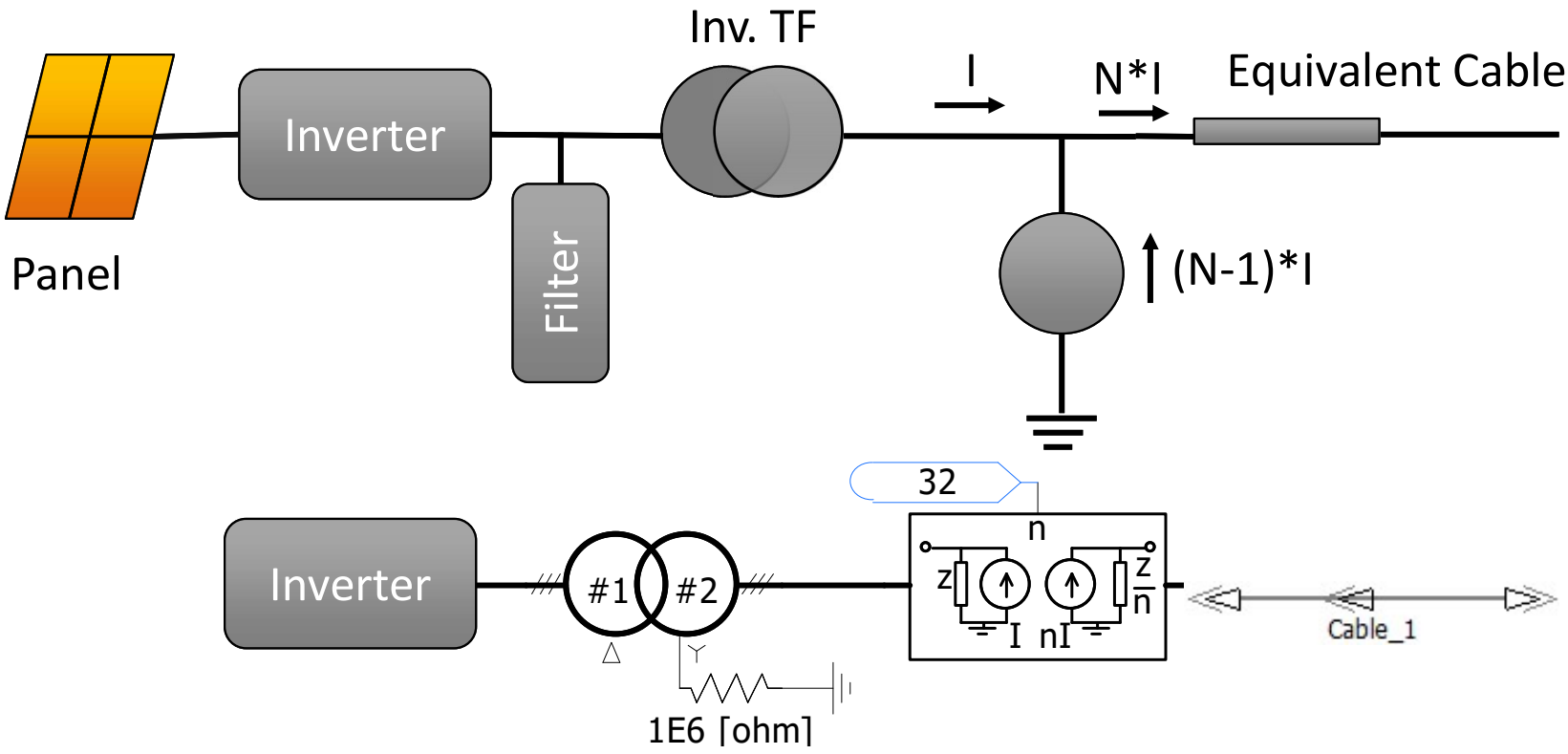
Solar Farm - Simulation

- Inverter
  - Multiple inverters



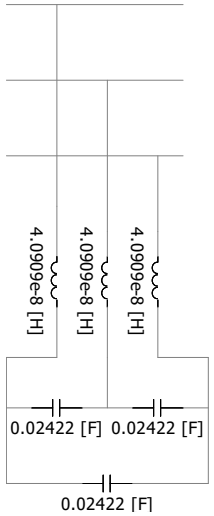
Solar Farm - Simulation

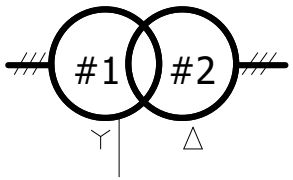
- Inverter Aggregation
  - Multiple inverters – heavy calculation burden

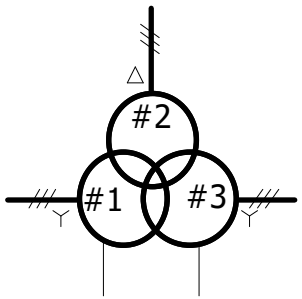


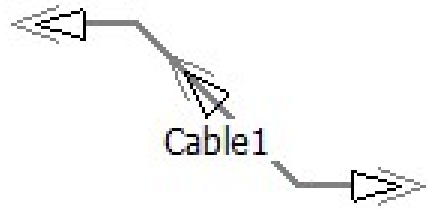
Solar Farm - Simulation

- Balance of the plant
  - Filter
  - Inverter transformer
  - Equivalent cable system
  - Grid transformer









Solar Farm - Simulation

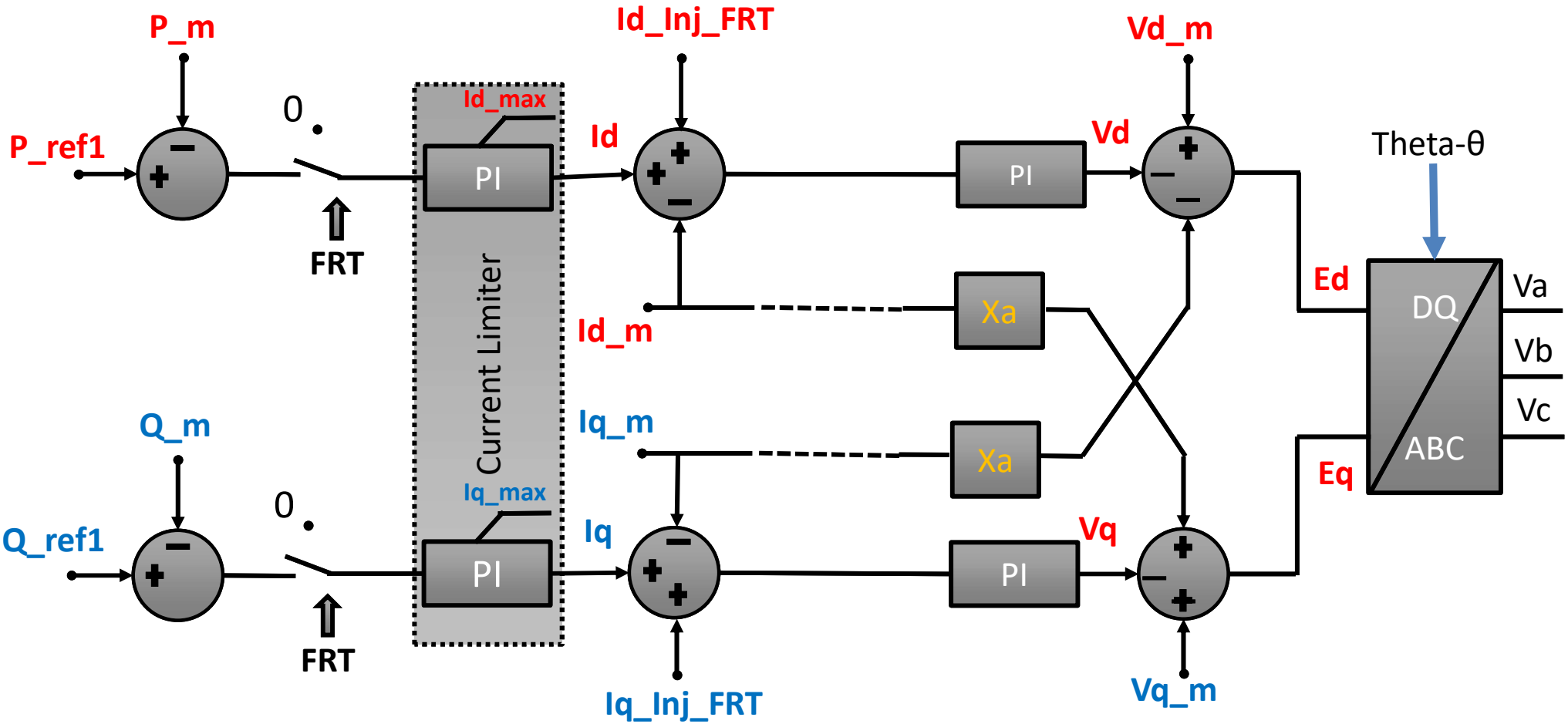
- Inverter Controller
  - Basic Concept
    - Active power control (P) command from Park Controller
    - Reactive power control (Q) command from Park Controller
  - Other Aspects
    - DC bus voltage control
    - Frequency response
    - HVRT/LVRT support

Solar Farm - Simulation

- Inverter Controller
  - Developed by the vendors
  - Black boxed models
  - Limited amount control parameters are exposed
  - Written in Fortran or actual compiled control code

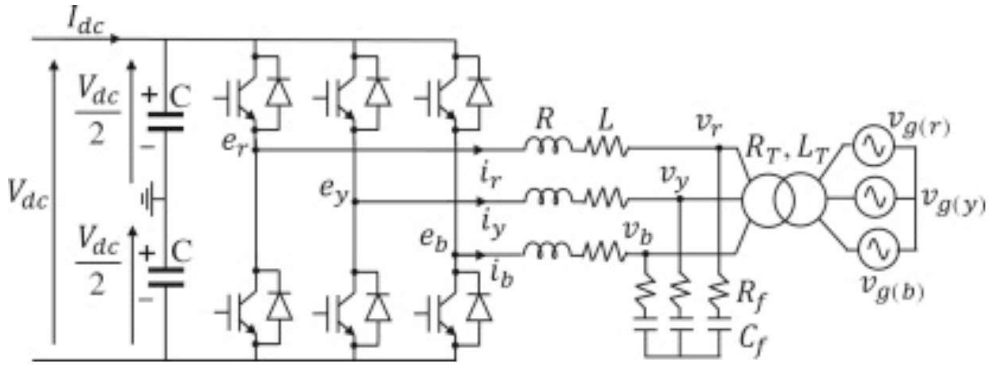
Solar Farm - Simulation

- Inverter Controller



Note: Current measurement is towards the plant

- Inverter Controller



$$\begin{bmatrix} e_r \\ e_y \\ e_b \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_r \\ i_y \\ i_b \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_r \\ i_y \\ i_b \end{bmatrix} + \begin{bmatrix} v_r \\ v_y \\ v_b \end{bmatrix}$$

$$[e_{ryb}] = [R]\,[i_{ryb}] + [L]\,\frac{d}{dt}[i_{ryb}] + [v_{ry\,b}]$$

- Inverter Controller

$$\begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ -\sin\theta & -\sin(\theta - 2\pi/3) & -\sin(\theta + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} x_r \\ x_y \\ x_b \end{bmatrix} \qquad [x_{dq\,0}] = [T(\theta)]\,[x_{ryb}]$$

$$\begin{bmatrix} x_r \\ x_y \\ x_b \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos(\theta - 2\pi/3) & -\sin(\theta - 2\pi/3) & 1 \\ \cos(\theta + 2\pi/3) & -\sin(\theta + 2\pi/3) & 1 \end{bmatrix} \begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} \qquad [x_{ryb}] = [T(\theta)]^{-1}\,[x_{dq\,0}]$$

$$[T(\theta)][e_{ryb}] = [T(\theta)]\left\{[R][i_{ryb}] + [L]\frac{d}{dt}[i_{ryb}]\right\} + [T(\theta)][v_{ryb}]$$

$$[e_{dq0}] = [R][i_{dq0}] + [L]\frac{d[T(\theta)i_{ryb}]}{dt} - [L]\left\{\frac{dT(\theta)}{dt}\right\}i_{ryb} + [v_{dq0}]$$

- Inverter Controller

$$e_{dq} = \begin{bmatrix} R & 0 \\ 0 & R \end{bmatrix} i_{dq} + \begin{bmatrix} L & 0 \\ 0 & L \end{bmatrix} \frac{di_{dq}}{dt} - \omega_s L \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} i_{dq} + v_{dq}$$

$$e_d = Ri_d + L\frac{d}{dt}i_d - \omega_s L i_q + v_d$$

$$e_q = Ri_q + L\frac{d}{dt}i_q + \omega_s L i_d + v_q$$

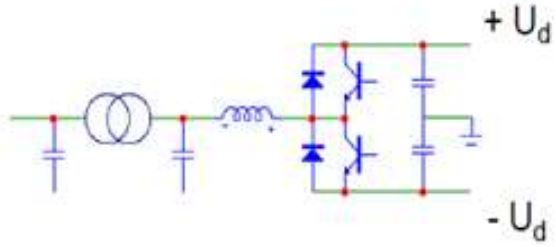
$$\begin{bmatrix} e_r \\ e_y \\ e_b \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_r \\ i_y \\ i_b \end{bmatrix} + \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_r \\ i_y \\ i_b \end{bmatrix} + \begin{bmatrix} v_r \\ v_y \\ v_b \end{bmatrix}$$

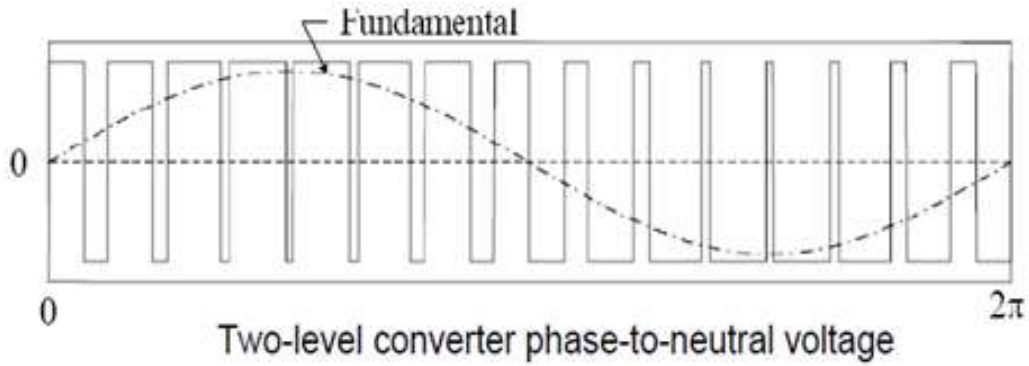
$$P = e_r i_r + e_y i_y + e_b i_b \qquad P = \frac{3}{2}[e_d i_d + e_q i_q]$$

$$Q = e_{ry} i_b + e_{yb} i_r + e_{br} i_y \qquad Q = \frac{3}{2}[-e_d i_q + e_q i_d]$$

- Inverter Controller - PWM

- **Two-level Converter, Generation 1**
  - Converter losses 3 %
  - High switching frequency
  - Filters required

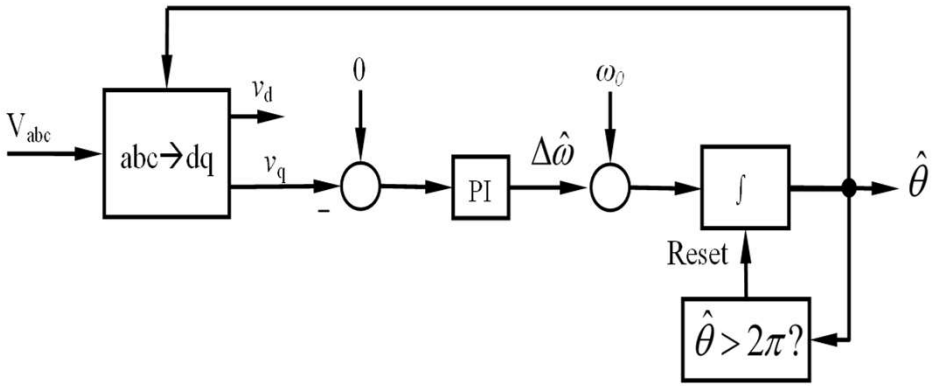


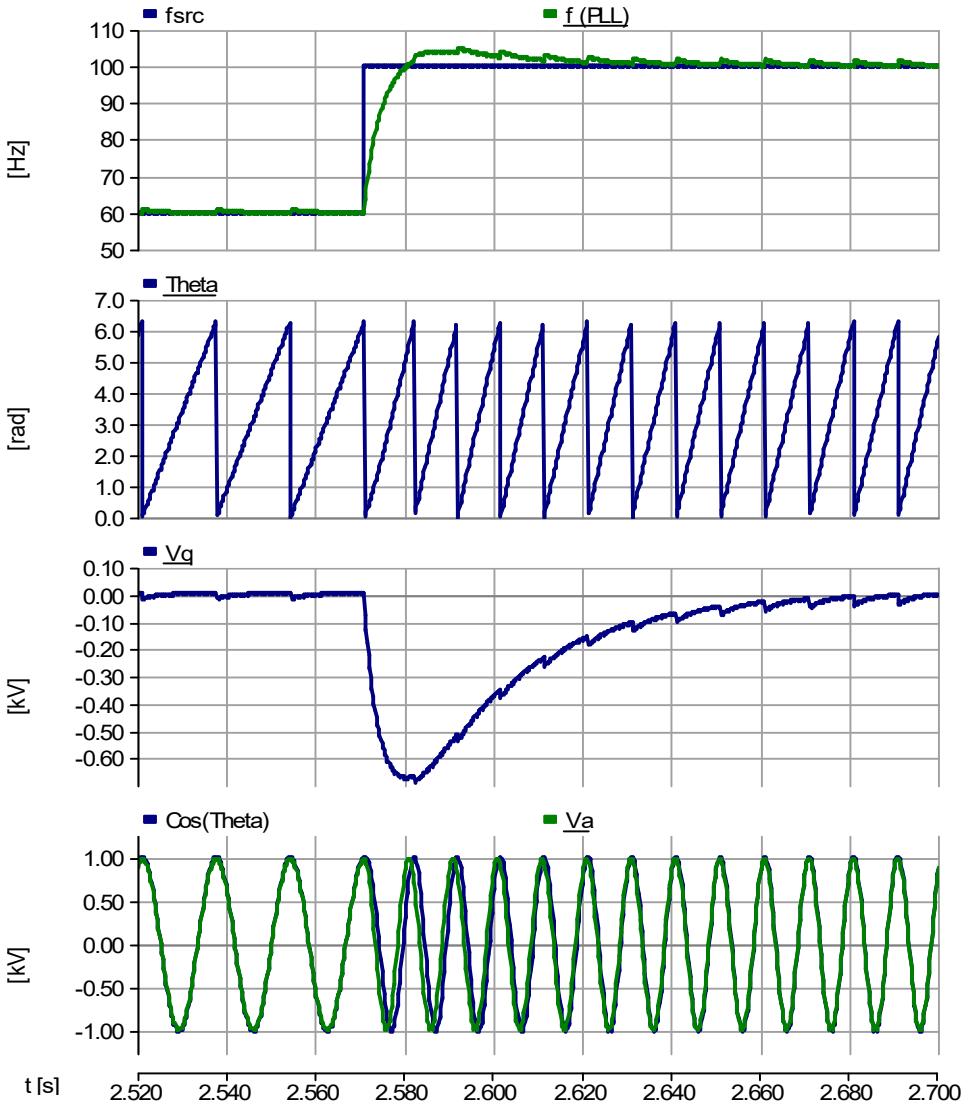


Two-level converter phase-to-neutral voltage

Solar Farm - Simulation

- PLL

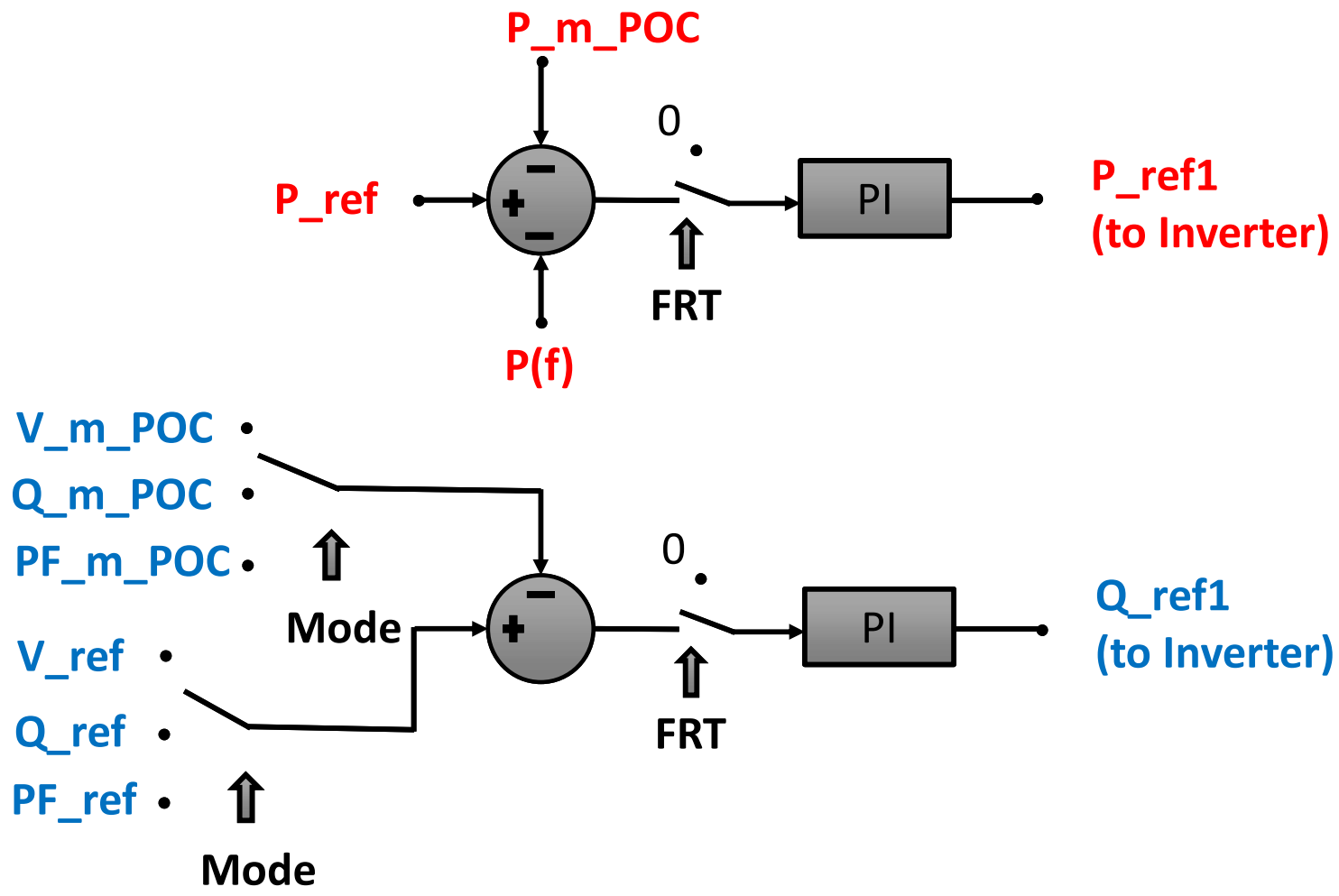




Solar Farm - Simulation

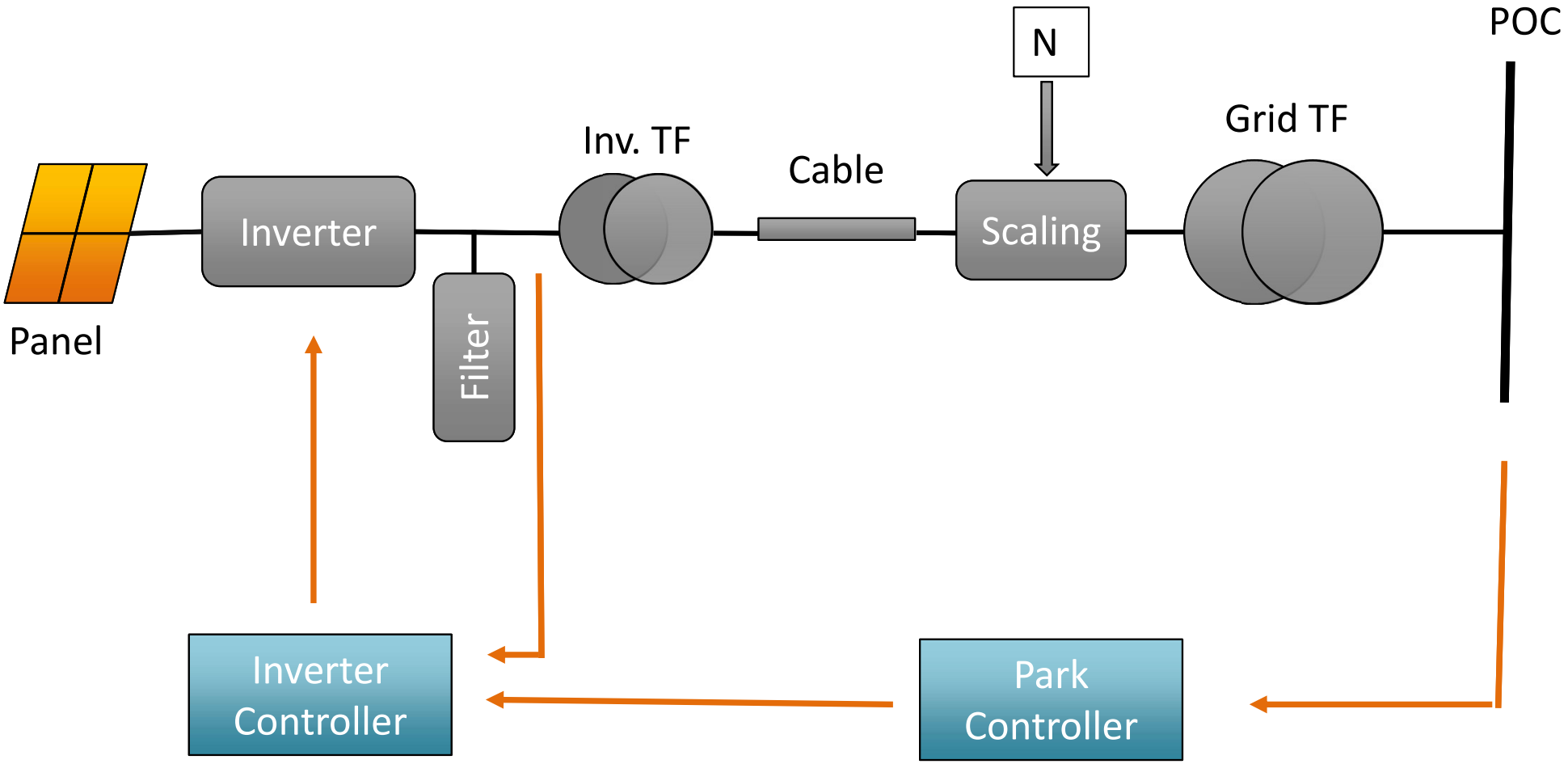
- Park Controller
  - Basic Concept
    - Active power control at POC
    - Voltage/Voltage droop/Reactive power/Power factor control at POC
  - Other Aspects
    - Frequency response
    - Anti-wind up during inverter HVRT/LVRT

- Park Controller - Schematic



Solar Farm - Simulations

- PSCAD Model

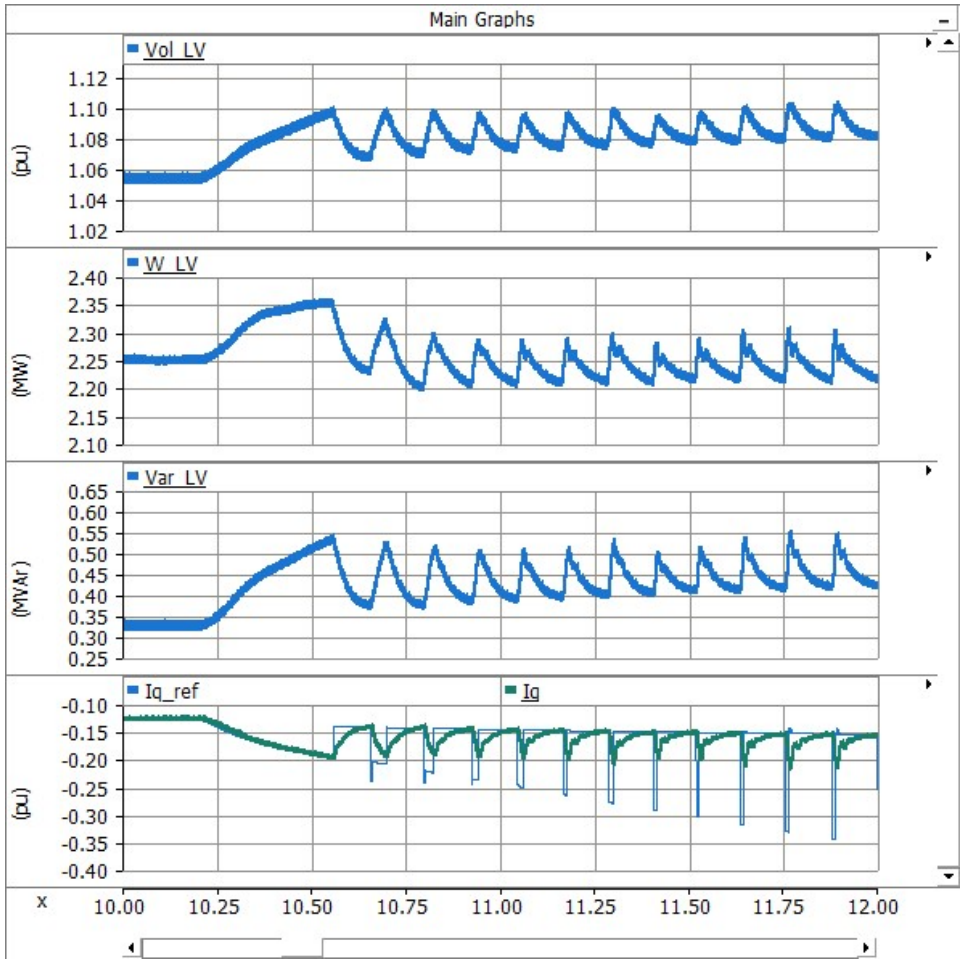


Solar Farm - Simulation

- Solar Farm Controls
  - Park controller
    - Active power/Reactive power control at POC (closed loop)
    - Slow response (PI controller Ti = 300-500 ms range)
  - Inverter Controller
    - Normal operation- follows the Park controller command
    - During HVRT/LVRT – open loop Id,Iq injection
    - Very Fast response

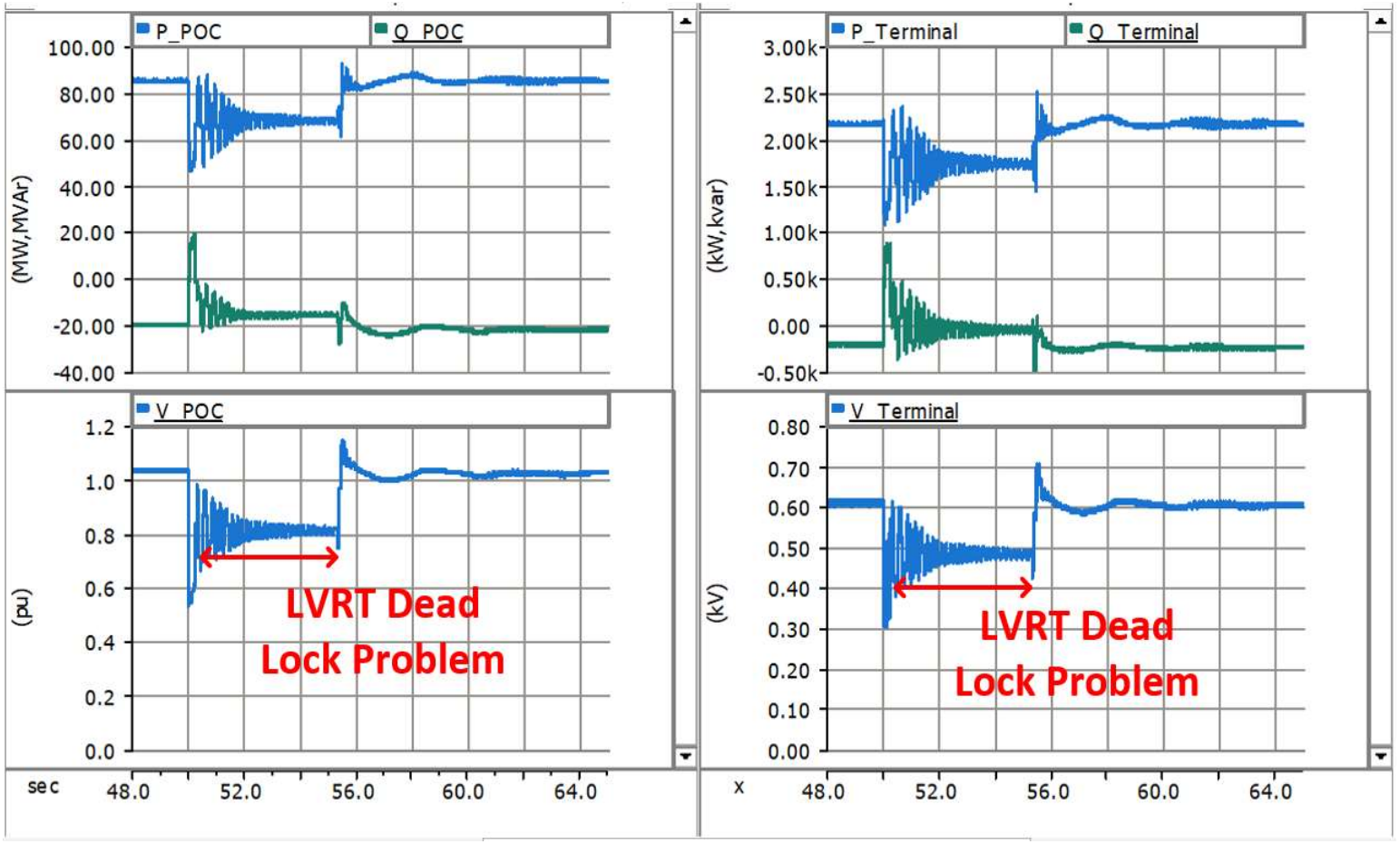
Solar Farm - Simulation

- Control Related Issues - HVRT



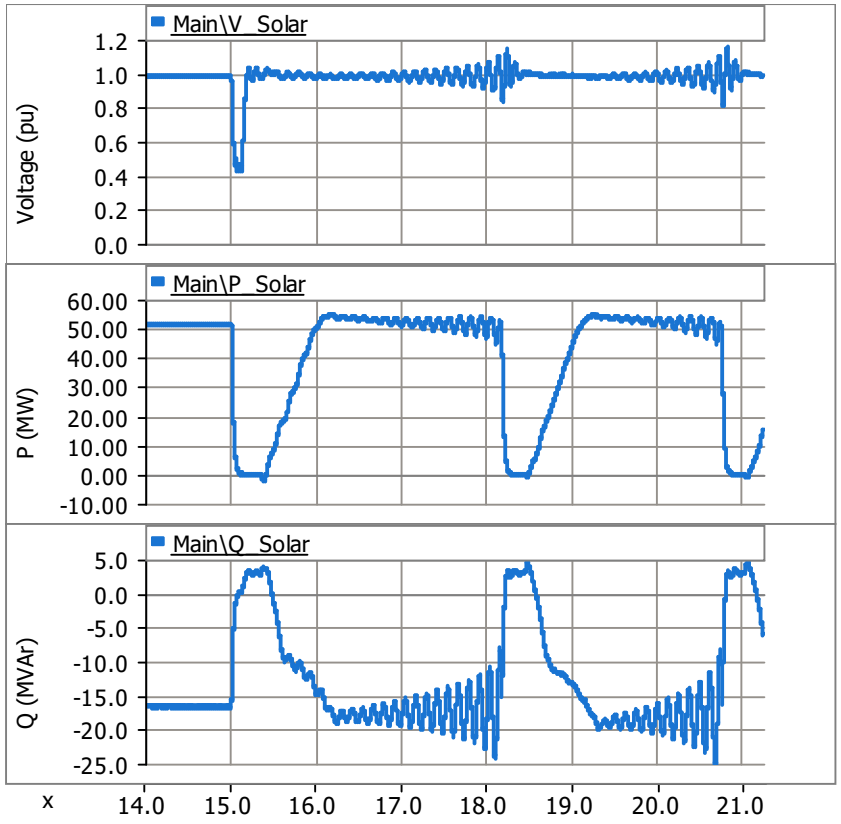
Solar Farm - Simulation

- Control Related Issues - LVRT
  - LVRT Dead Lock Problem
  - Released until one surrounding solar farm trips due to low voltage

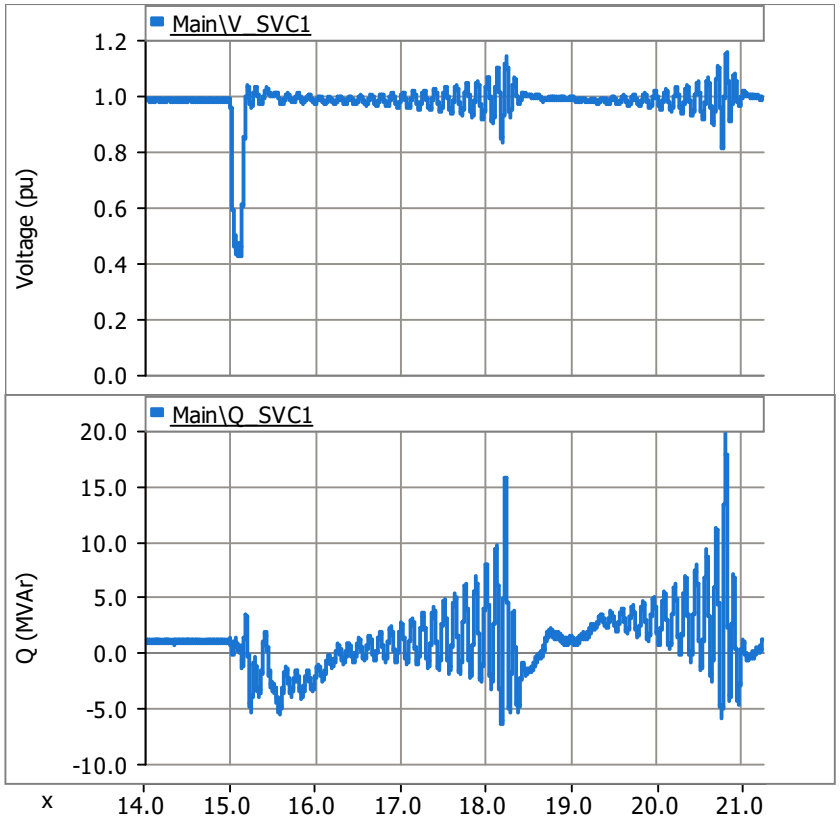


Solar Farm - Simulation

- Control Related Issues – Control Interactions



Solar Farm



SVC

Solar Farm - Simulation

- SVC/STATCOM/Sync Condenser

	MSC/MSR	Synchronous Condenser	SVC	STATCOM
Application	Compensation for predictable load changes	Dynamic compensation	Fast dynamic compensation	Fast dynamic compensation
Features		Fault recovery support, Short-circuit power	Fault recovery support	Fault recovery support
V/I Characteristic	Overvoltage performance (MSR)	Overload capability	Overvoltage performance	Under-voltage performance
Control Range	In steps of MSC & MSR capacities	Continuous in capacity range	Continuous in capacity range	Continuous in symmetrical output range
O & M cost	Very Low	Comparably high	Low	Low
Losses @ 0 MVAr	0%	1%	0.3%	0.15%
Availability	>99%	<98%	>99%	>99%

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