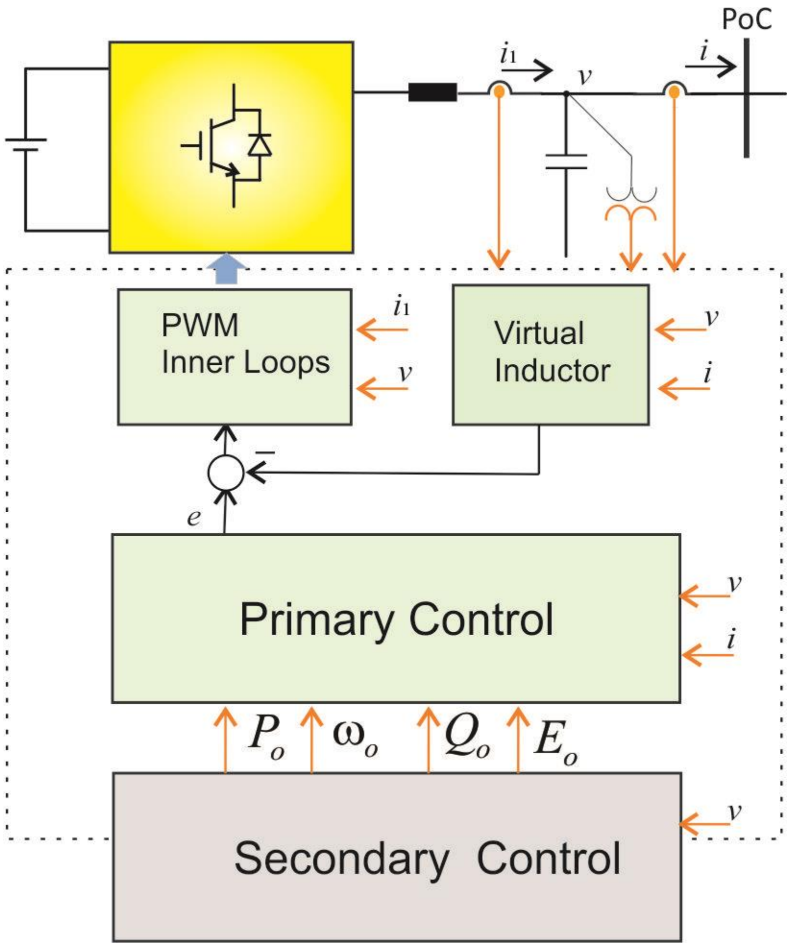
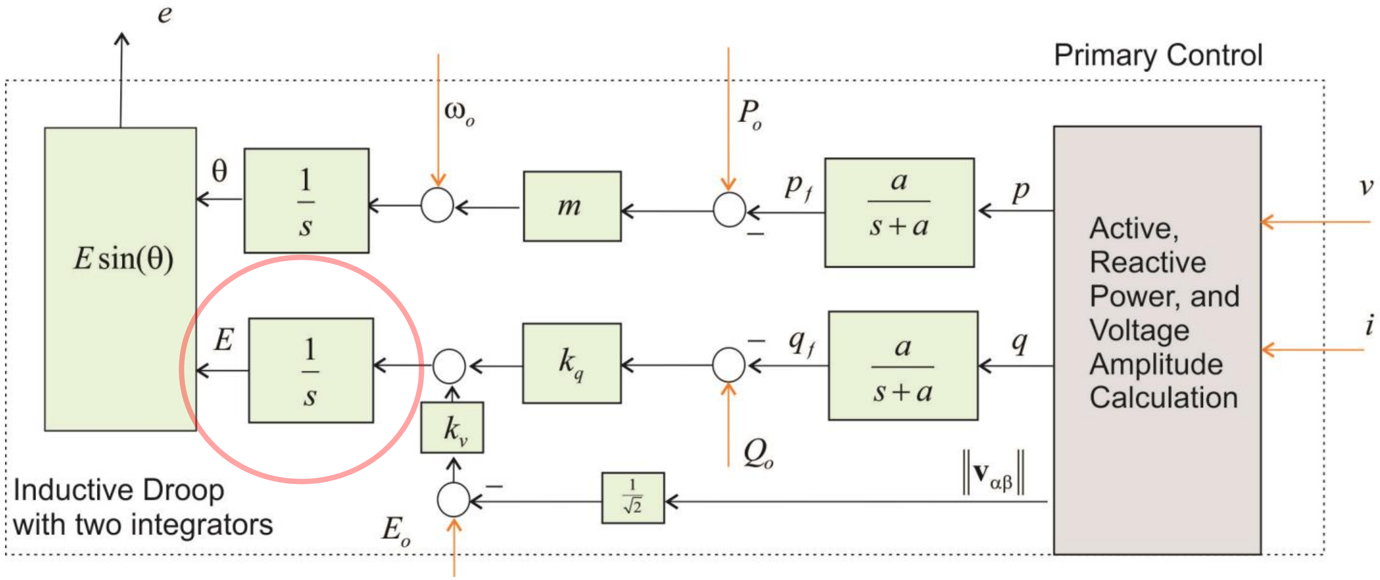
Grid-Forming Inverter with Inductive Droop Control



Integrator in the reactive power – voltage loop



Dynamic model – Grid-Forming Inverter with inductive droop

Integrator is add in the reactive power – voltage loop

$$\frac{d\delta}{dt} = \omega + b_{11}$$

$$\frac{d\omega}{dt} = a_{21}\omega + a_{22}e\sin(\delta) + b_{21}$$

$$\frac{de_d}{dt} = a_{21}e_d + a_{32}e\cos(\delta) + b_{31}$$

$$\frac{de}{dt} = e_d$$

$$b_{11} = -\omega_r$$

$$a_{21} = -a$$

$$b_{21} = a\left[\omega_o + mP_o\right]$$

$$a_{32} = -\frac{k_q a V}{X_L}$$

$$b_{31} = k_q a\left[Q_o + \frac{V^2}{X_L} + \frac{1}{n}(E_o - V)\right]$$

$$n = \frac{k_q}{k_v}$$

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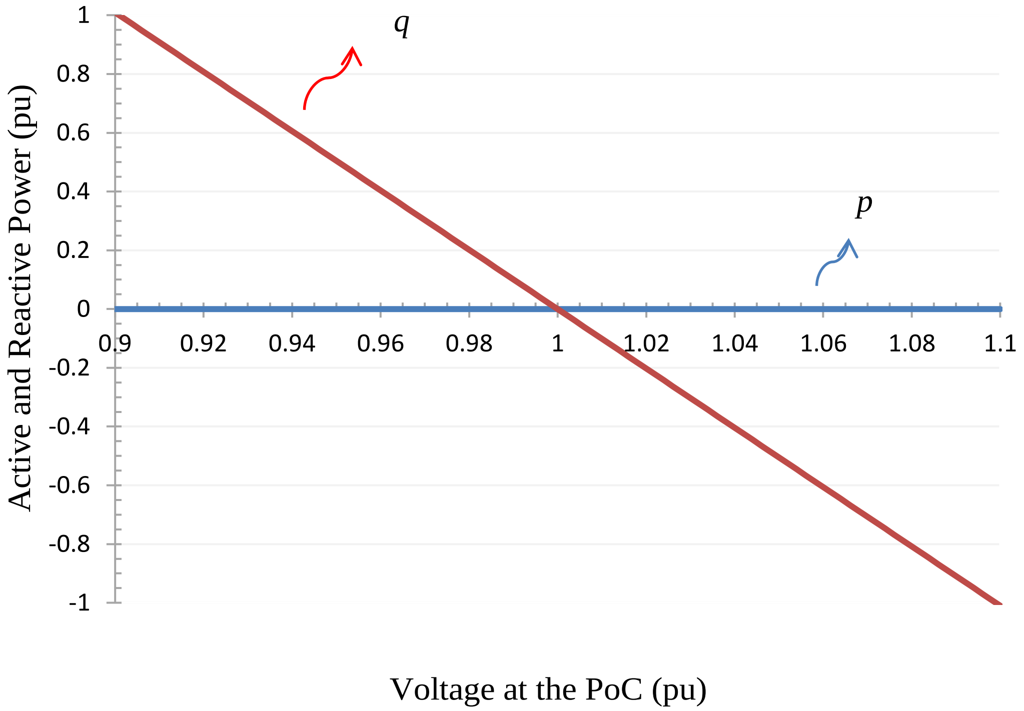
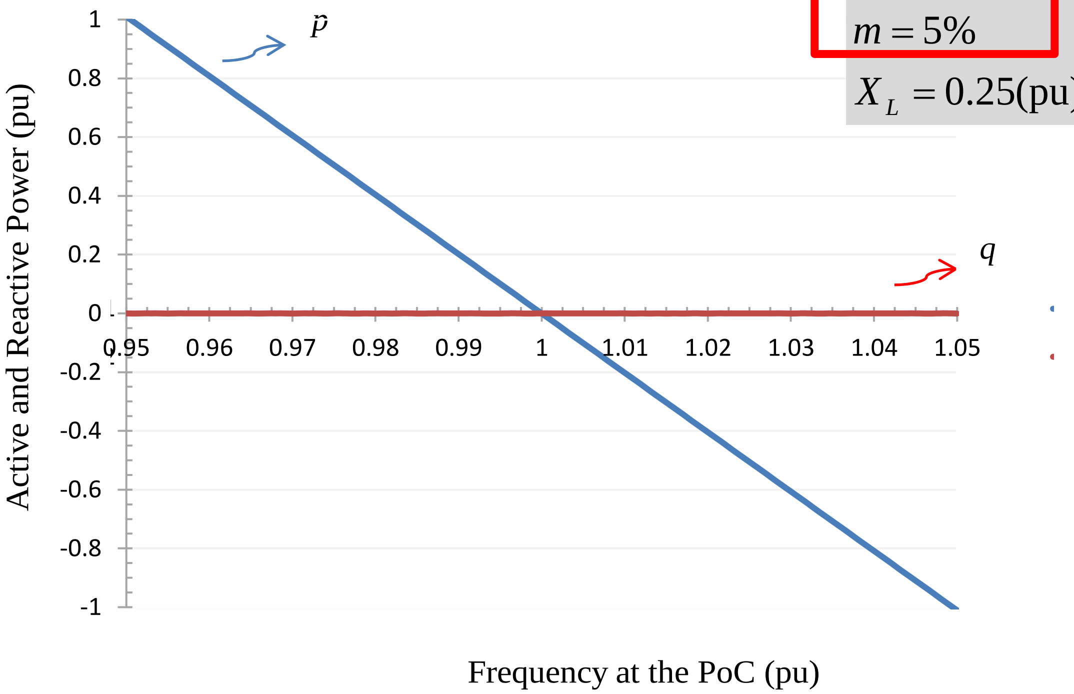
Steady-State Performance

$$E_o = 1$$
$$\omega_o = 1$$
$$P_o = 0$$
$$Q_o = 0$$
$$n = 10\%$$
$$m = 5\%$$
$$X_L = 0.25(\text{pu})$$





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Example

The association between the states on the modes can be seen from the participation factors:

$$\begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_3 \\ \lambda_4 \end{bmatrix} = \begin{bmatrix} -94.25 + j68.55 \\ -94.25 - j68.55 \\ -8.39 \\ -180.10 \end{bmatrix} \Rightarrow \begin{array}{c} \begin{matrix} \lambda_1 & \lambda_2 & \lambda_3 & \lambda_4 \end{matrix} \\ \left\{ \begin{matrix} 0.86 & 0.86 & 0 & 0 \\ 0.86 & 0.86 & 0 & 0 \\ 0 & 0 & 0.05 & 1.058 \\ 0 & 0 & 1.058 & 0.05 \end{matrix} \right\} \end{array} \begin{matrix} \delta \\ \omega \\ e_d \\ e \end{matrix}$$

$k_v = 20$

$n = 10\%$

$m = 5\%$

$a = 2\pi 30$

$X_L = 0.25 \text{ (pu)}$

$Q_o = 0$

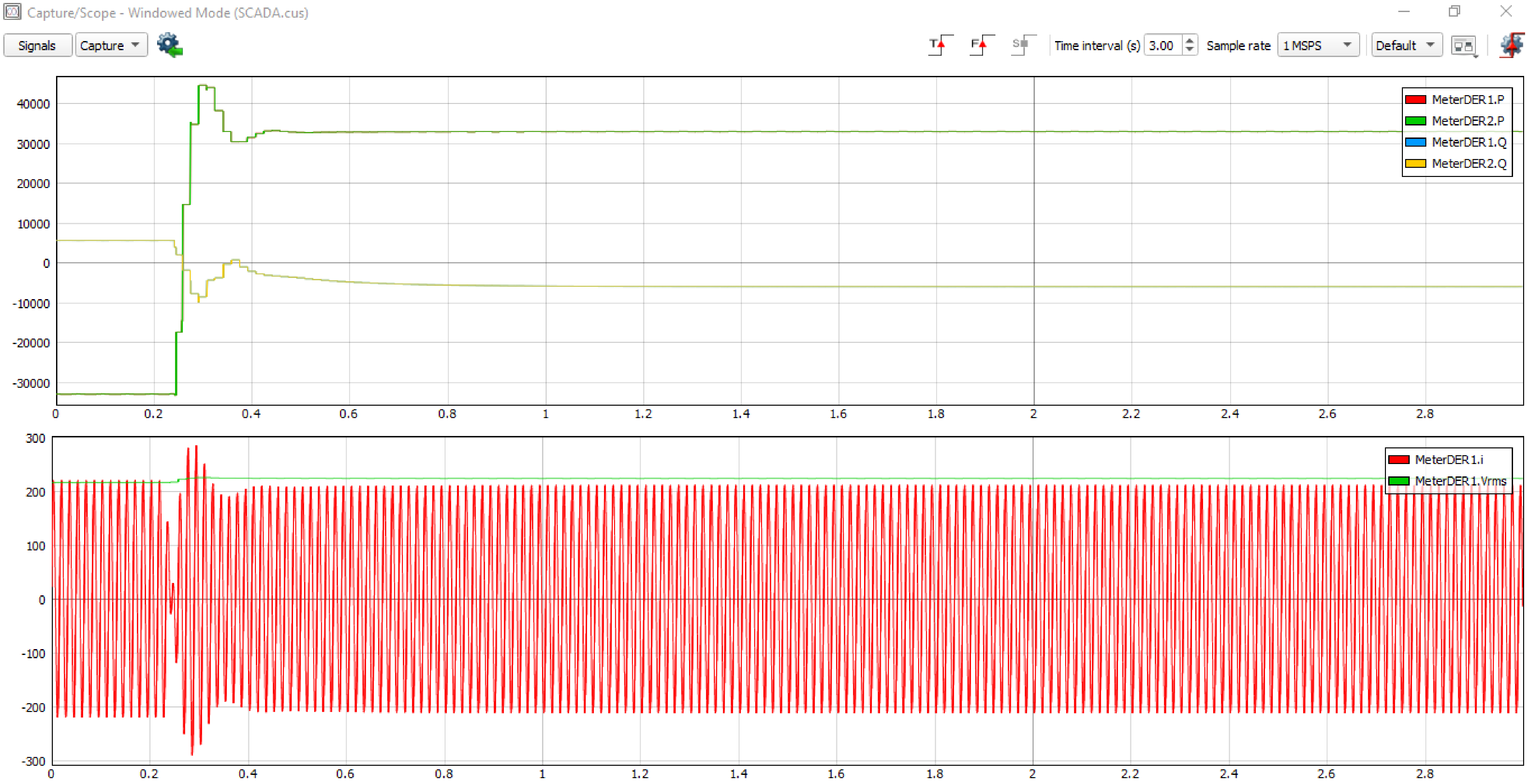
$P_o = 1 \text{ (pu)}$

$V = 1 \text{ (pu)}$

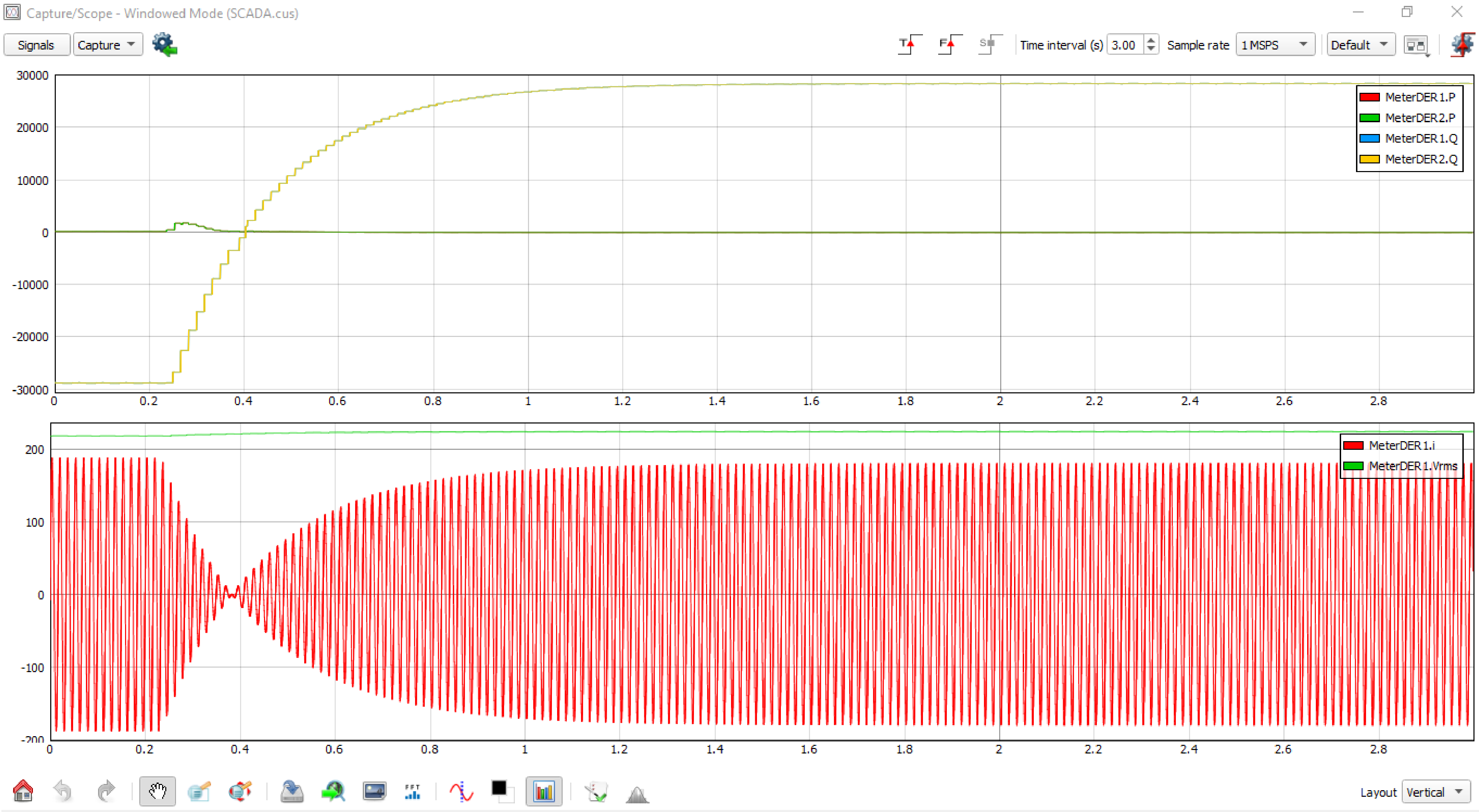
$E_o = 1 \text{ (pu)}$

$\omega_o = 1 \text{ (pu)}$

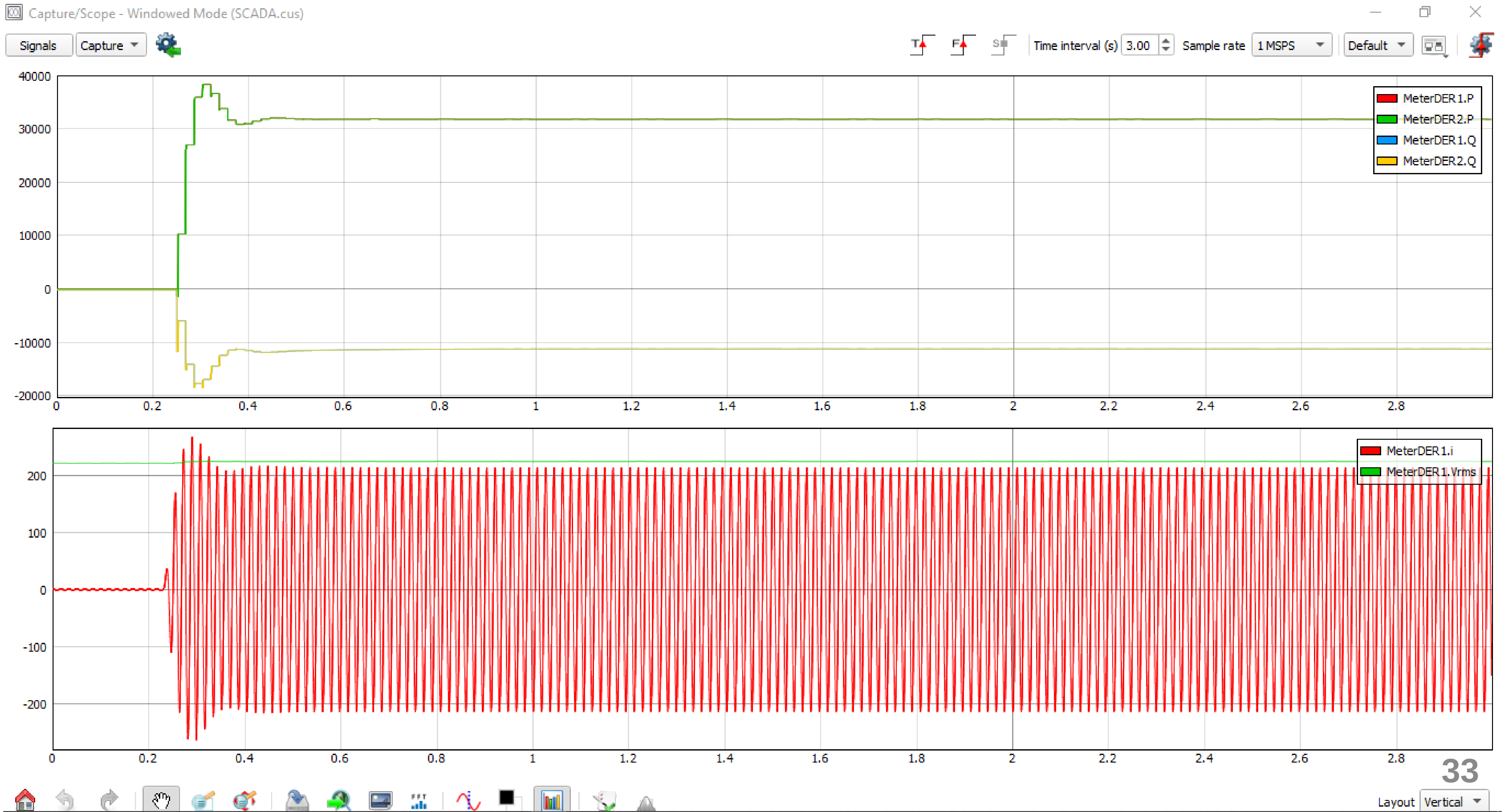
Transient Response



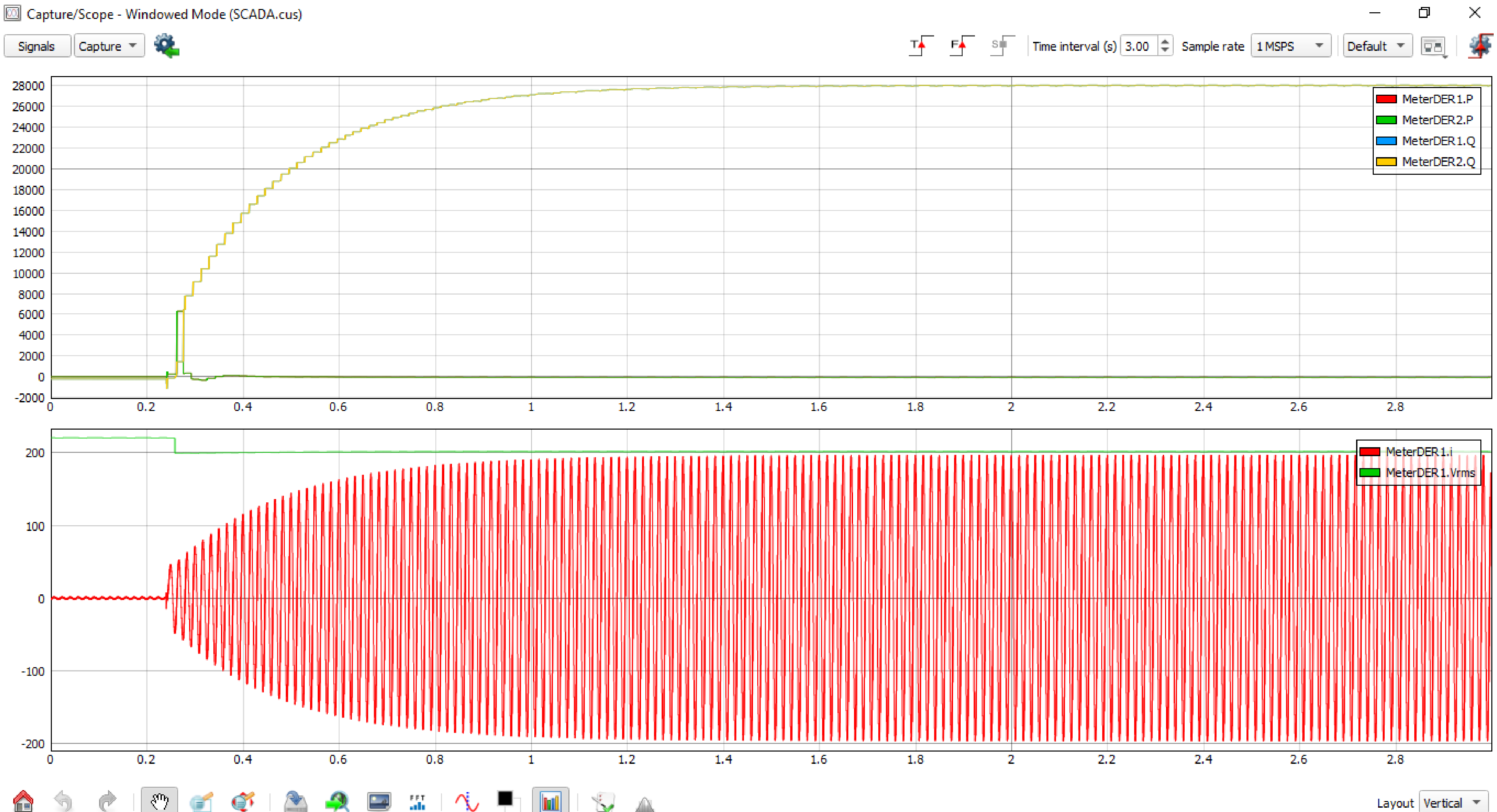
Transient Response



Transient Response



Transient Response



Summary

- With the use of a virtual inductor, the impact of the X/R ratio of the grid, seen from the PoC, is reduced.

- The selection of the droop coefficients impacts both the transient and steady-state behavior of the grid-forming inverter.

- For the derivation of small-signal analyzes of the grid-forming inverter with droop control, the inner voltage and current loops can be neglected.

- The use of an additional integrator in the reactive power voltage loop improves the droop characteristics in steady-state.

- The implementation of the droop control is straightforward.

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