# NARMA-L2 Controller

*NARMA discrete-time model:*

$$y(k+d) = N[y(k), y(k-1), \ldots, y(k-n+1), u(k), u(k-1), \ldots, u(k-n+1)]$$

*Non Linear* *Auto-Regressive* *Moving Average*

*Narendra e Mukhopahyay, 1997: NARMA L2 Norm Model*

$$\begin{aligned} y(k+d) = {} & f[y(k), y(k-1),\ldots, y(k-n+1), u(k-1),\ldots, u(k-m+1)] \\ & + g[y(k), y(k-1),\ldots, y(k-n+1), u(k-1), \ldots, u(k-m+1)] \cdot u(k) \end{aligned}$$

*Control Law:*

$$u(k) = \frac{y_r(k+d) - f[y(k), y(k-1),\ldots, y(k-n+1), u(k-1),\ldots, u(k-n+1)]}{g[y(k), y(k-1),\ldots, y(k-n+1), u(k-1),\ldots, u(k-n+1)]}$$

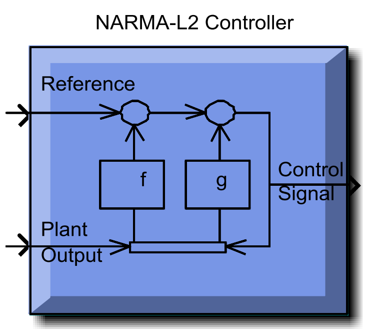
*Appliyng the Control Law to the NARMA-LW model results:* $y_r(k+d) \equiv y(k+d)$

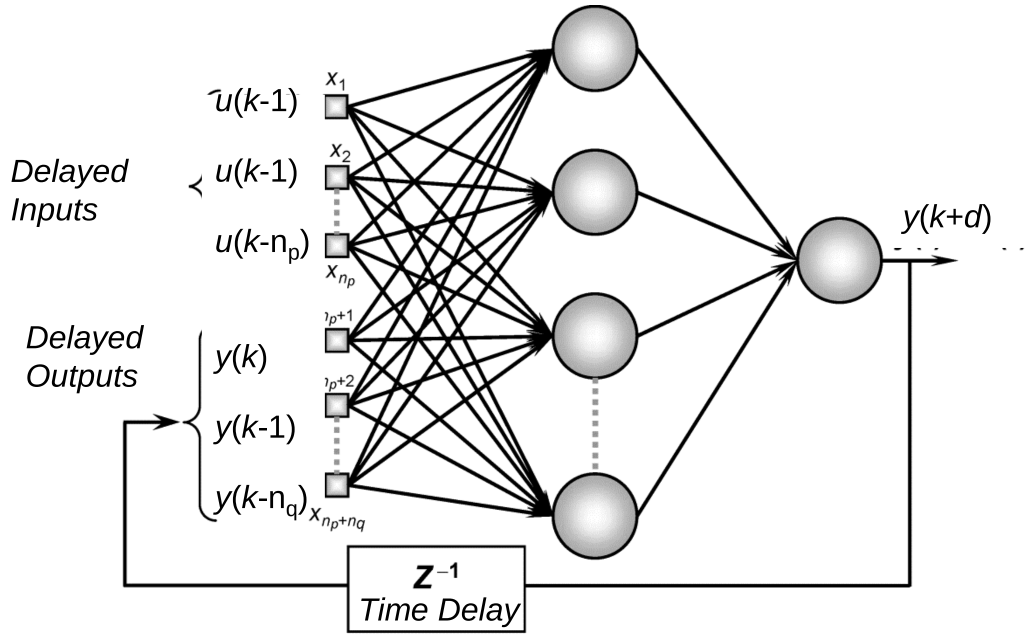
*y follows $y_r$ exactly!!*

# NARMA-L2 Controller

$$u(k) = \frac{y_r(k+d) - f[y(k), y(k-1), ..., y(k-n+1), u(k-1), ..., u(k-n+1)]}{g[y(k), y(k-1), ..., y(k-n+1), u(k-1), ..., u(k-n+1)]}$$

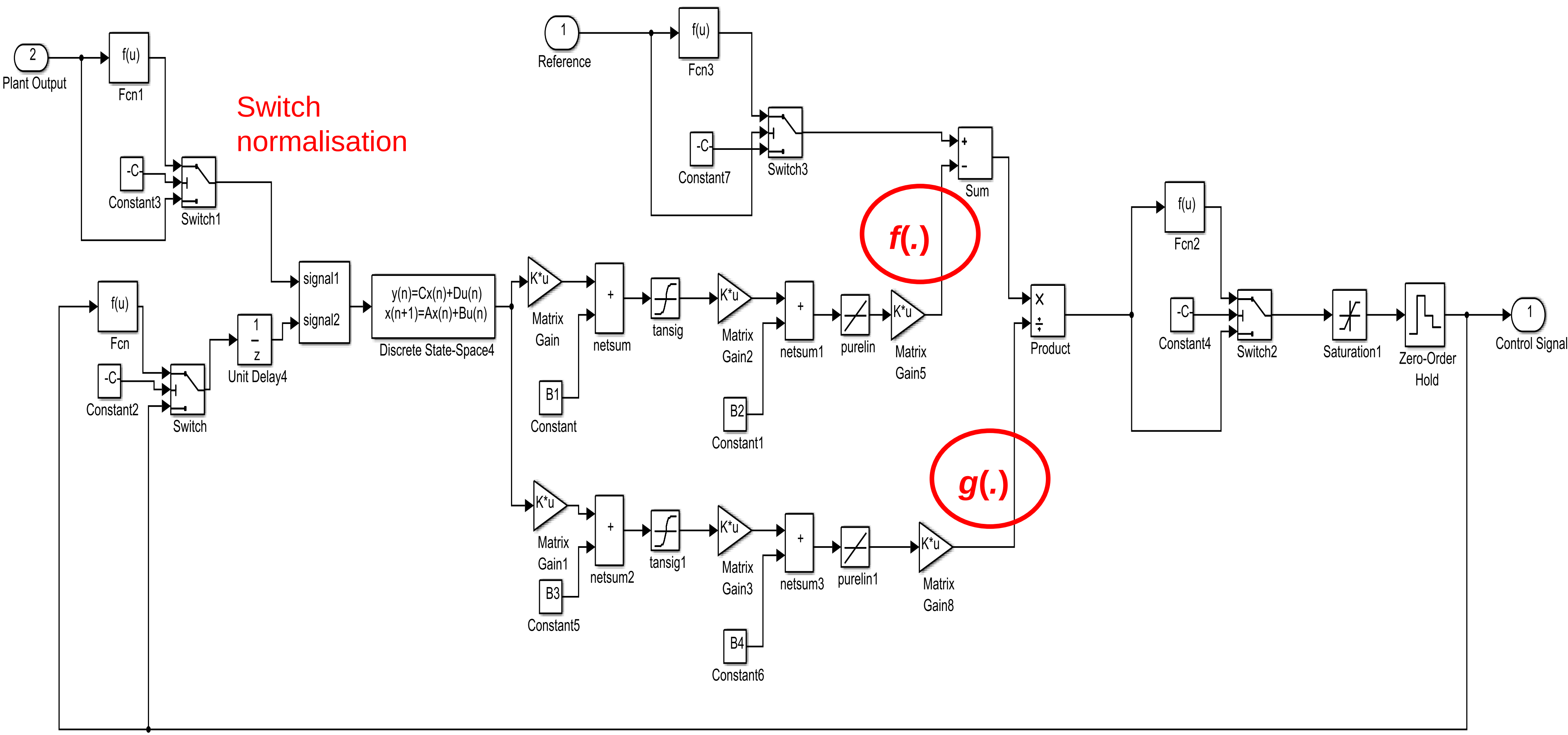
*ANN can be used to learn f(.): the additive non-linear term and g(.) the multiplicative non-linear term*



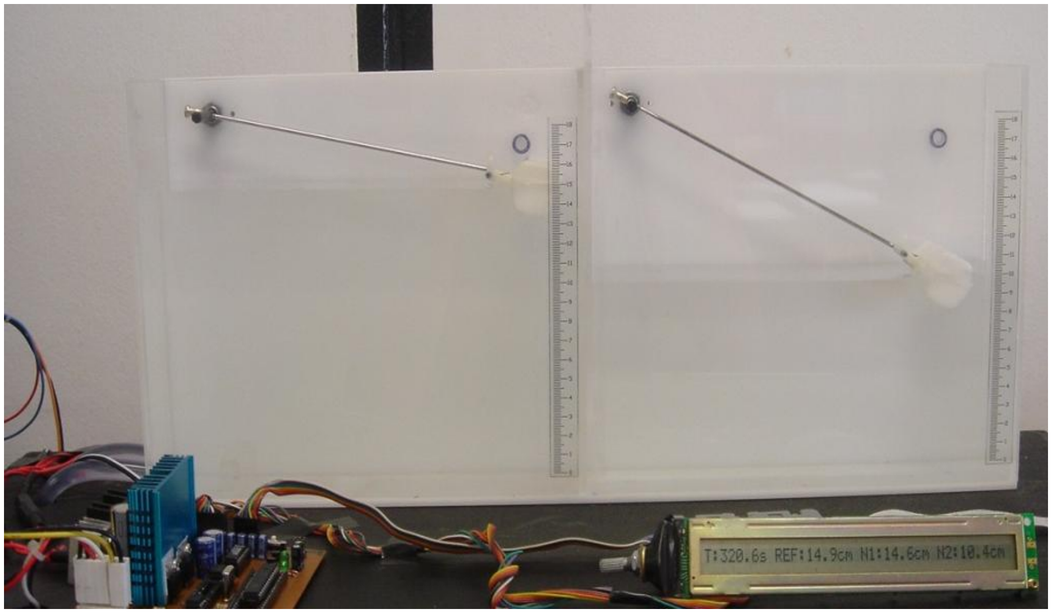



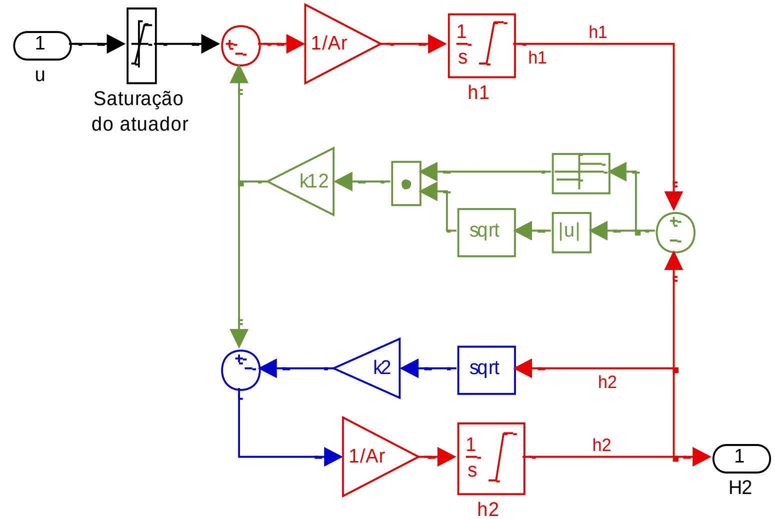

$$y(k+d) = N[y(k), y(k-1), ..., y(k-n+1), u(k), u(k-1), ..., u(k-n+1)]$$

# NARMA-L2 controller



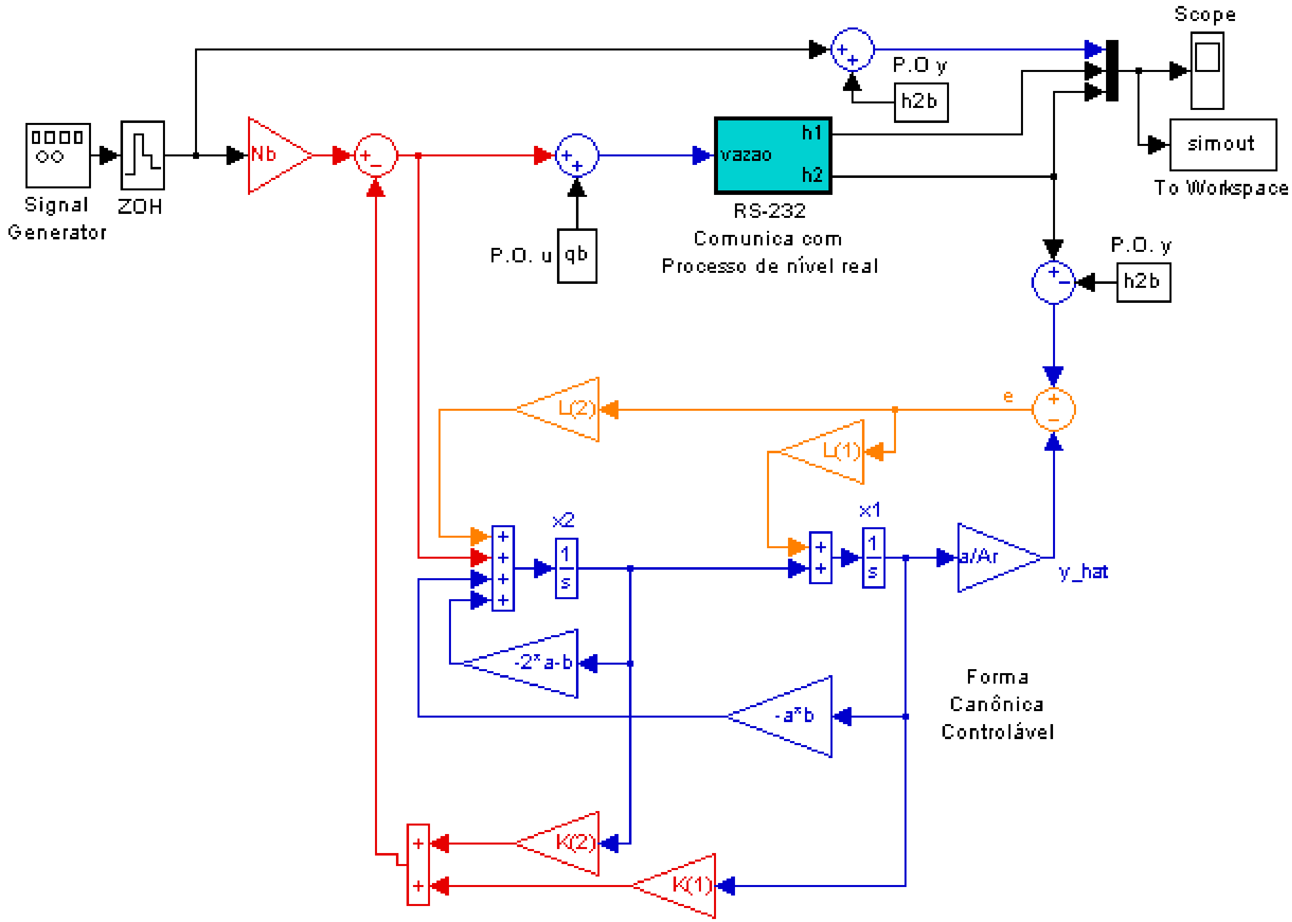
# Ex: Liquid Level Control



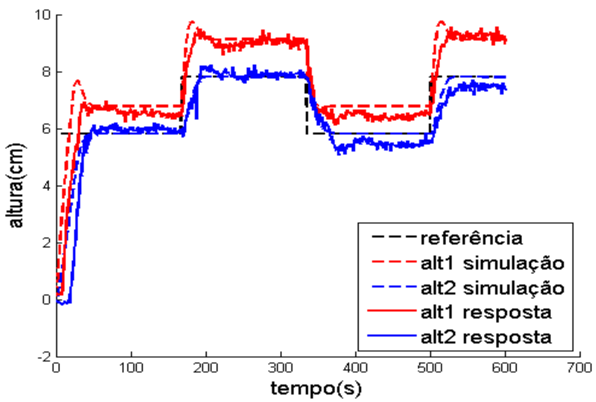

$$
\begin{cases}
A\dfrac{dh_1}{dt} = q_i - k_{12}\sqrt{h_1 - h_2} \\
A\dfrac{dh_2}{dt} = k_{12}\sqrt{h_1 - h_2} - k_2\sqrt{h_2}
\end{cases}
$$

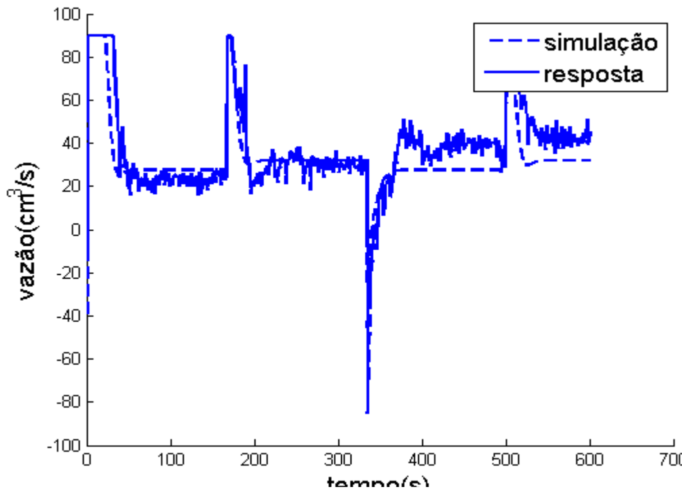
# Integrated Interface to Process

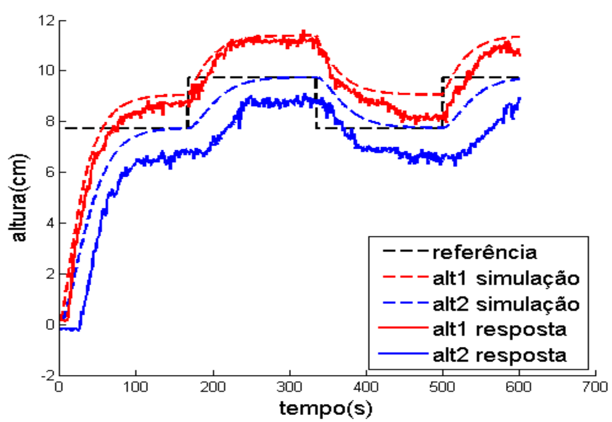


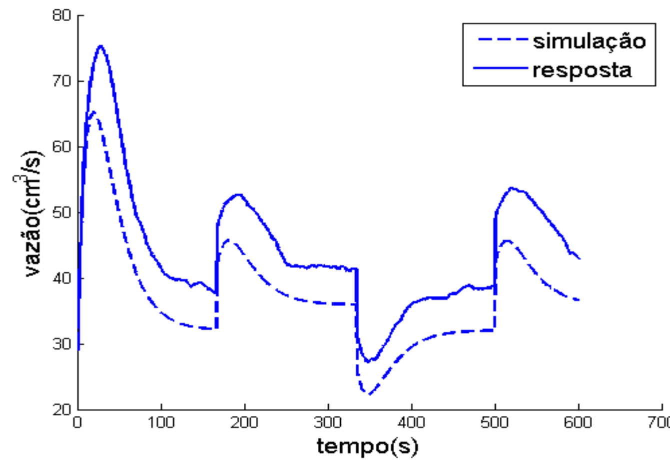

State Space Controller – Designed for a specififc Operating Point

# State-Space Results



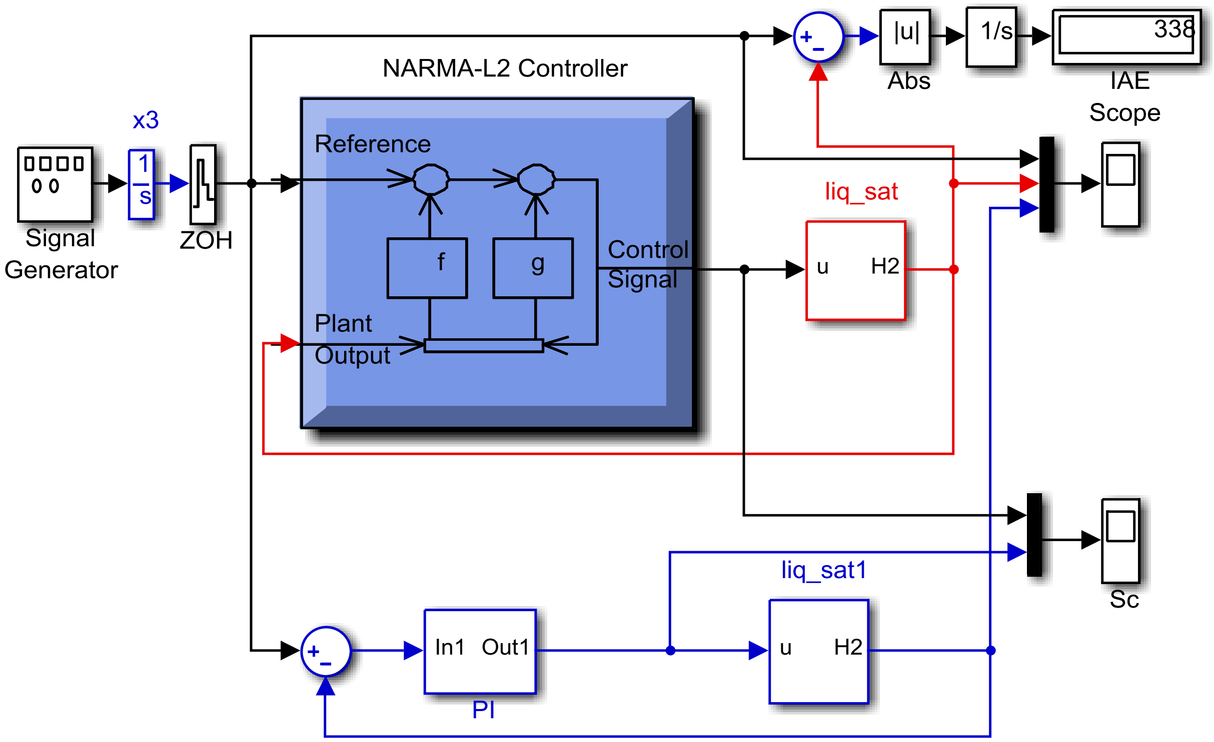



# NARMA-L2Liquid Level Control

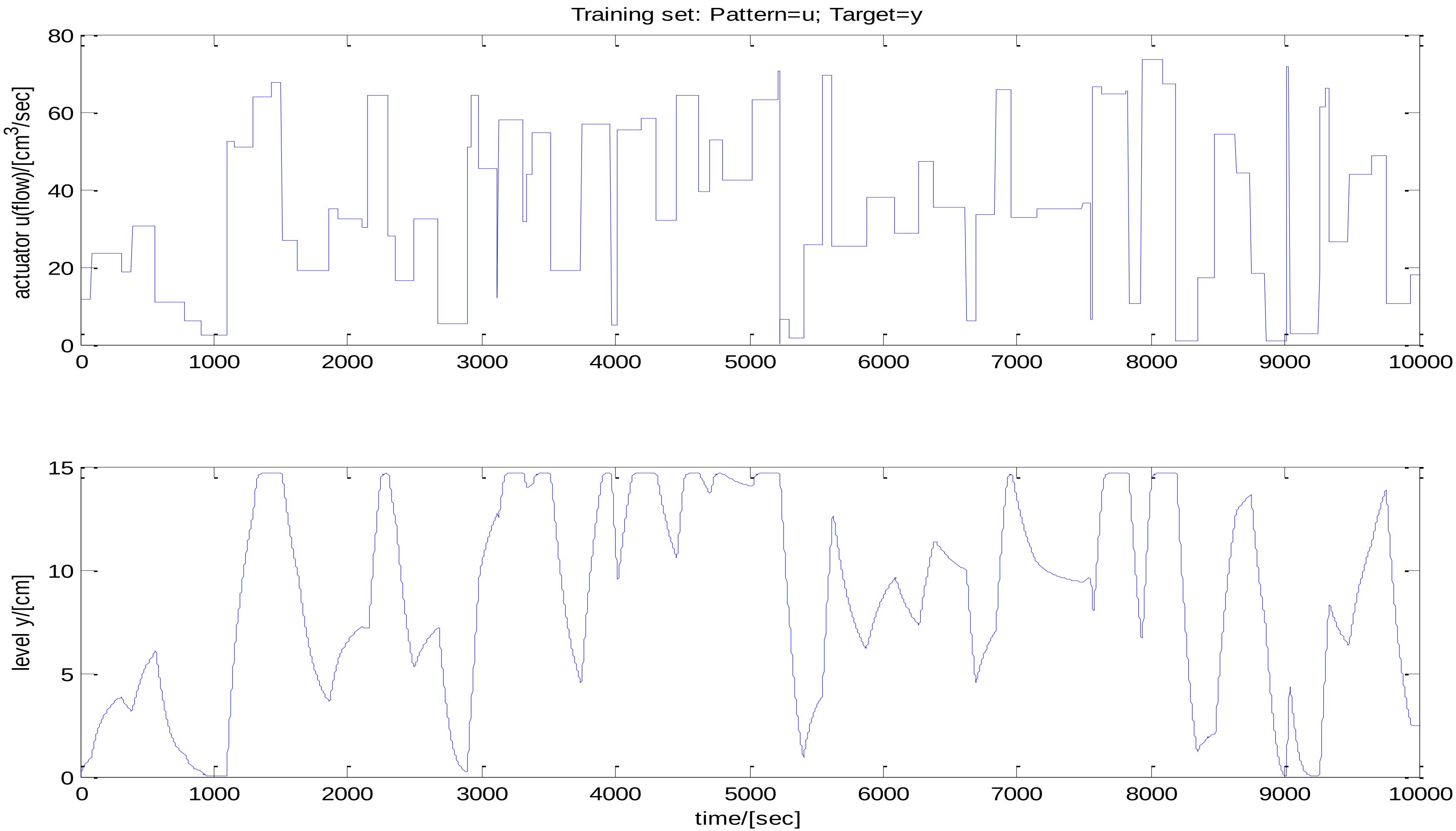
Purpose: compare PI and NARMA-L2 control.



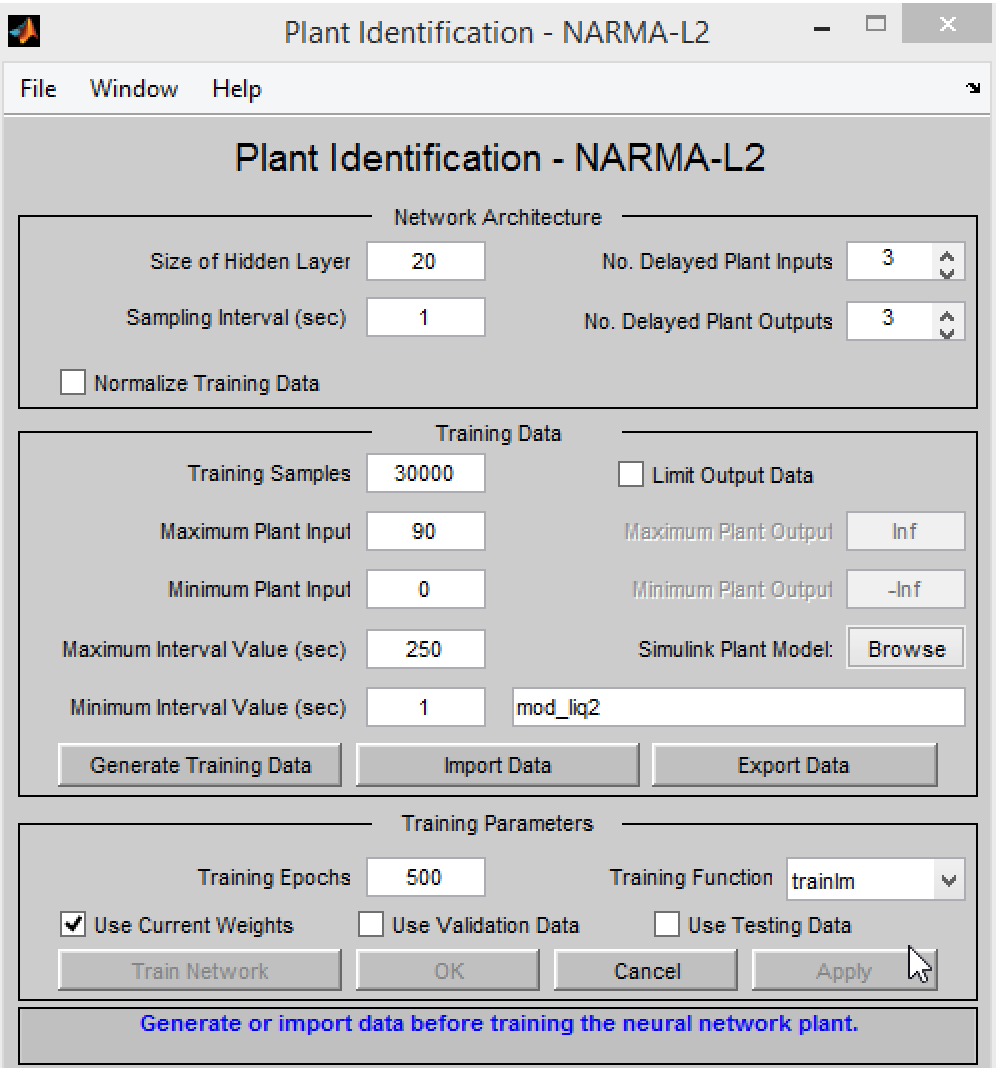

Because of the square root in the model a different behaviour is expect for different reference levels!

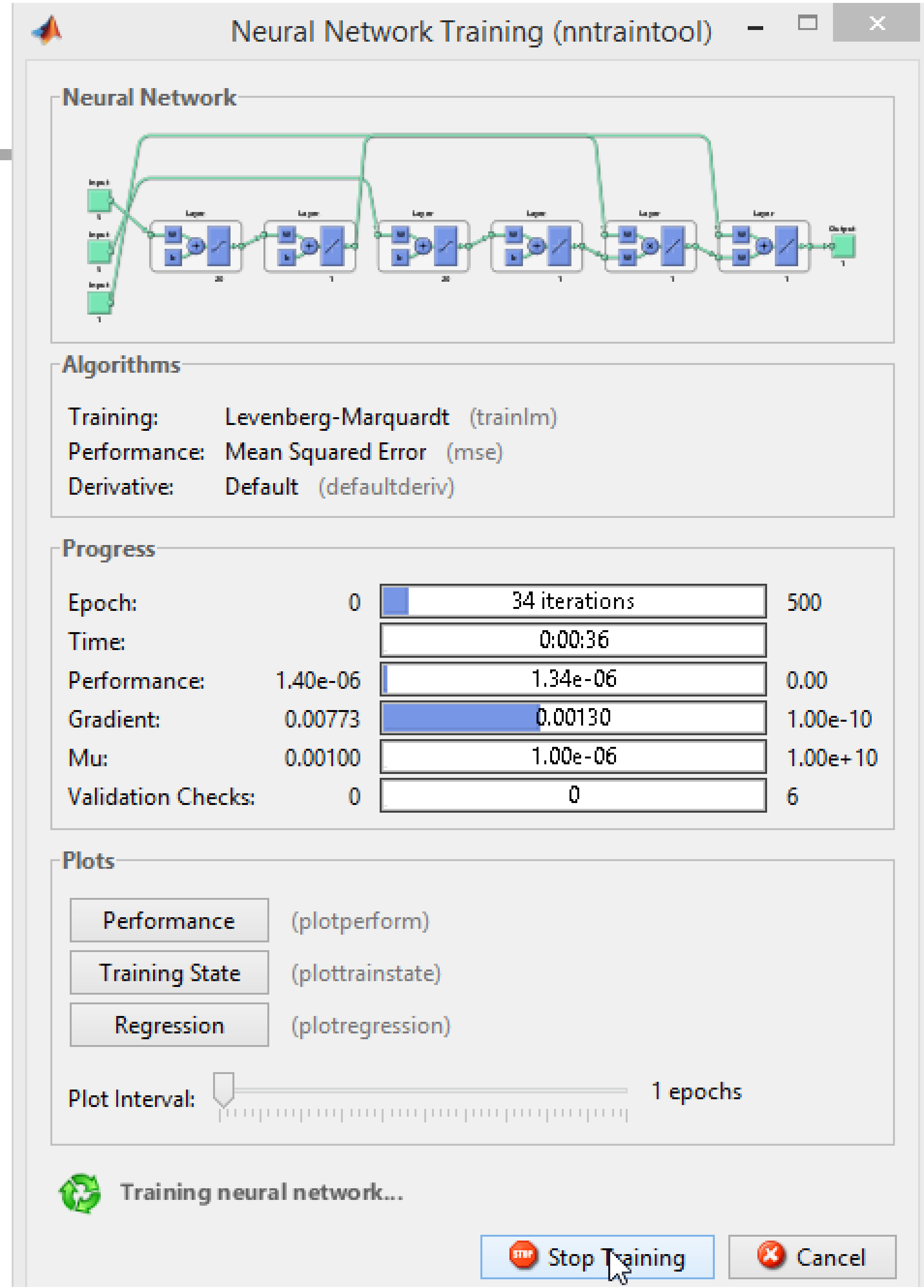
# Generated Training Sets

Cover the time domain range (dynamics) and amplitude range (operating points).

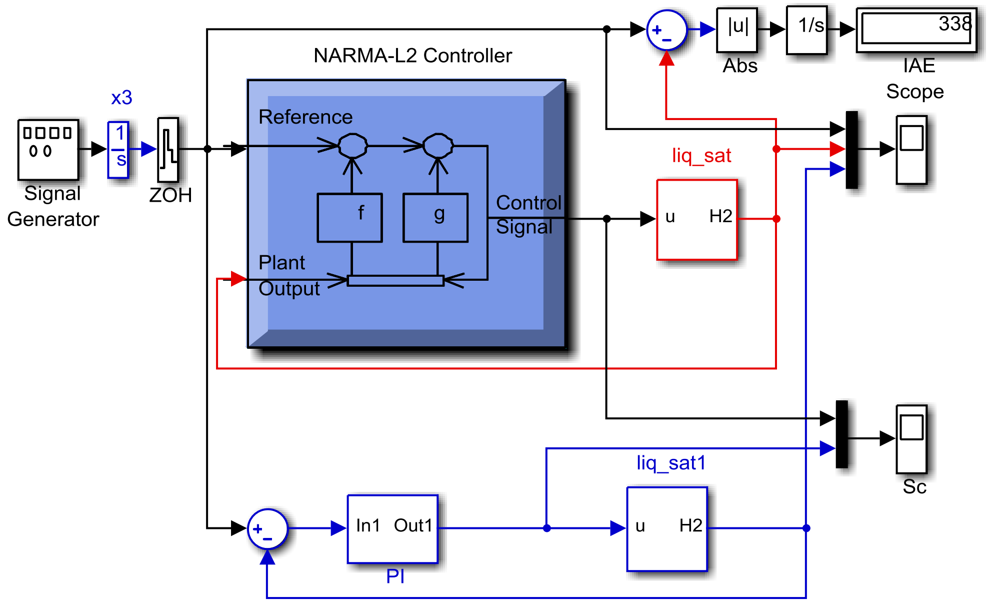


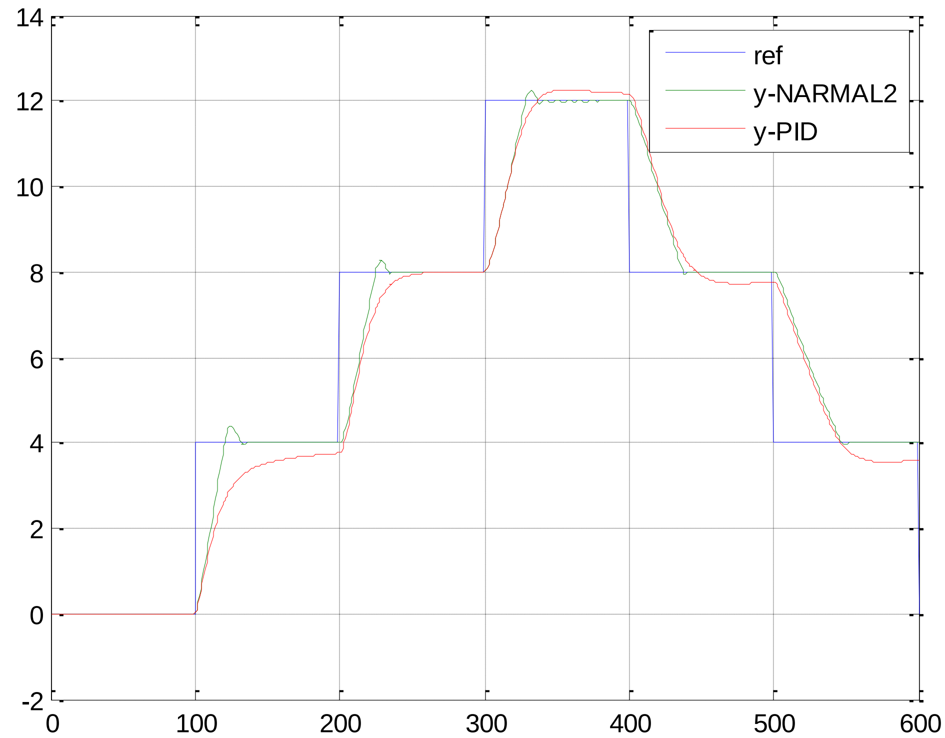
# NARMA-L2 tool



# NARMA-L2 Liquid Level Control




-PI gives no error in steady state, but with very different dynamics.
-NARMA-L2 has almost the same behaviour in all operating points.

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# PI vs NARMA-L2 Control Signal

- NARMA-L2 uses often the maximum available u.
- PI calculate signals that are clamped by the saturation.
- NARMA-L2 tends to “chattering”

-NARMA-L2 design parameters:

- sampling rate
- input/output delays
- training sets
- training algorithms

NARMA-L2 can be trained with real data!!
Real processes are quite more complex than models!