Minnesota State University Mankato

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# Power Line Communication Input Impedance Adjustment via Network Load Measurements


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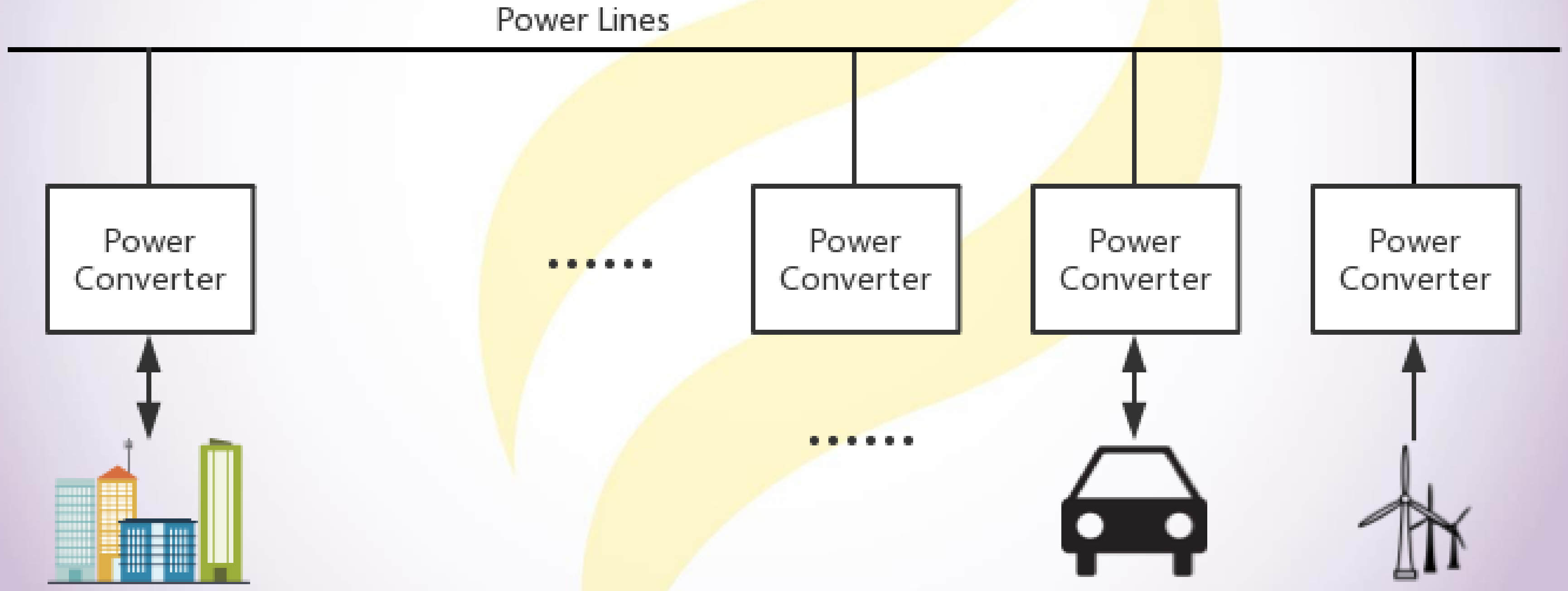
Big ideas. Real-world thinking.

# Outline

1. Introduction
2. Network model
3. Numerical optimization
4. Simulation results
5. Conclusions

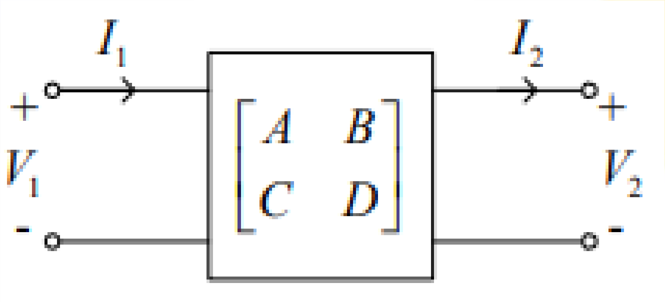
# Introduction

Power line communication (PLC) is a technology by reusing existing infrastructures (i.e. power lines) whose primary purpose is the delivery of AC or DC electric power, to communicate data.



# Network model

Transmission (ABCD) matrix of two-port network is




The ABCD matrix is defined as

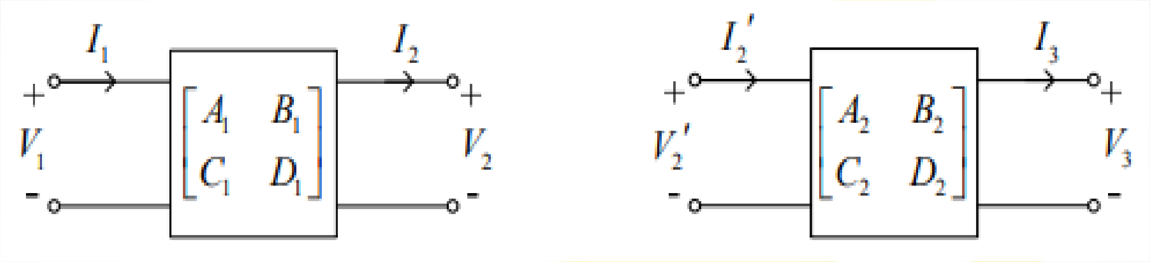
$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \cdot \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

where

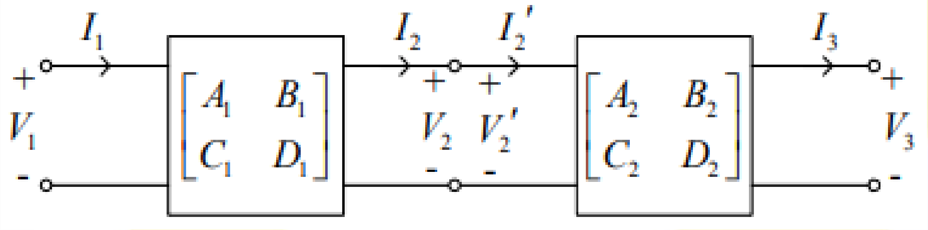
$$A = \frac{V_1}{V_2}|_{I_2=0}, B = \frac{V_1}{I_2}|_{V_2=0}$$
$$C = \frac{I_1}{V_2}|_{I_2=0}, D = \frac{I_1}{I_2}|_{V_2=0}$$

# Network model

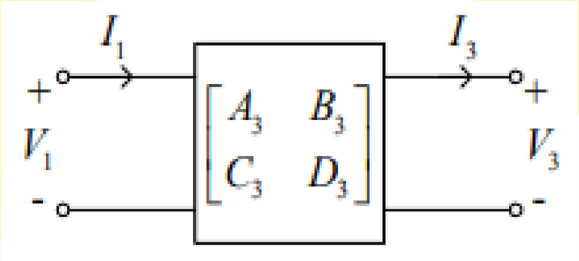
## Cascade property of two-port networks




(1)




(2)

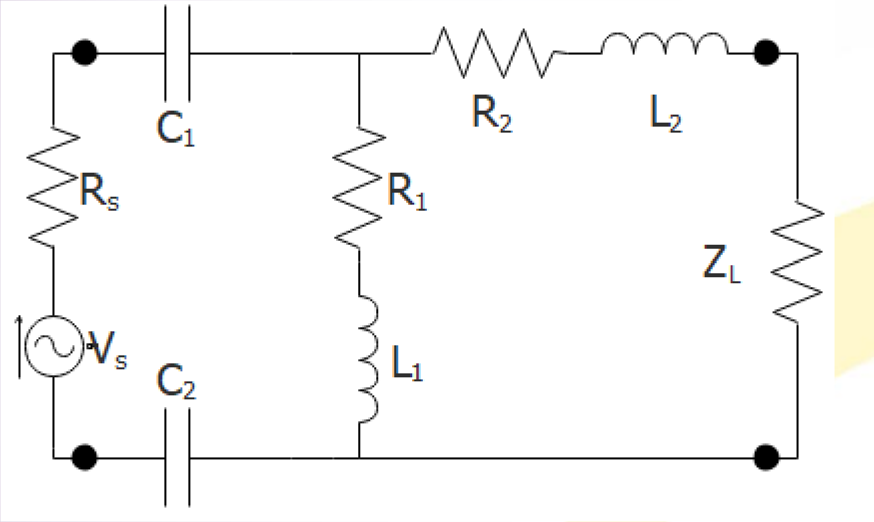



(3)

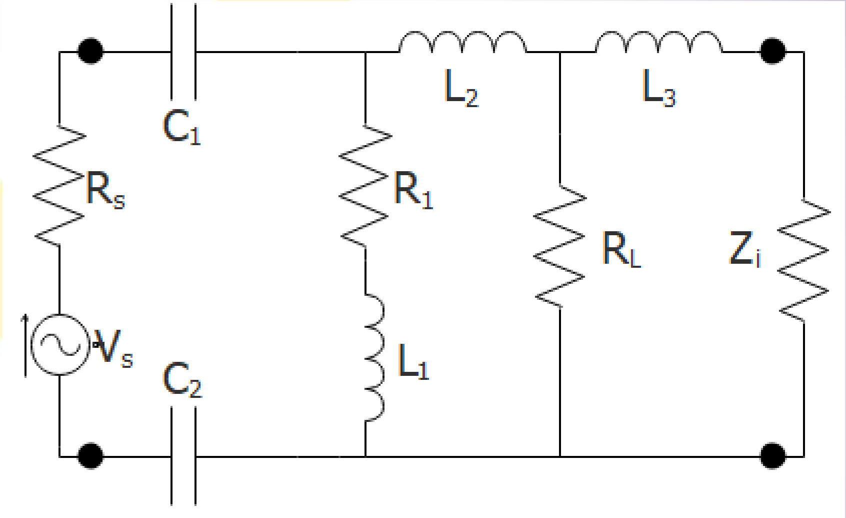
$$\begin{bmatrix} A_3 & B_3 \\ C_3 & D_3 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdot \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$$

# Network model

## Original model [1]




## Our model




where, we assumed a feeder load, $R_L$, which varies but can be measured.

[1] I. Cavdar (2004), ”Performance Analysis of FSK Power Line Communications Systems Over the Time-Varying Channels: Measurements and Modeling”, IEEE Trans. on Power Delivery, vol. 19, no. 1.

# Network model

We can write the input power expression and the power transfer function in the following, respectively

$$V_I \cdot I_I = ACV_O^2 + ADV_O I_O + BCV_O I_O + BDI_O^2 \tag{1}$$

$$\frac{S_O}{S_I} = \frac{V_O I_O}{(AD+BC)V_O I_O + ACV_O^2 + BDI_O^2} \tag{2}$$

Then, given that $\frac{V_O}{I_O} = Z_i$, we have

$$\frac{S_O}{S_I} = \frac{\frac{V_O^2}{Z_i}}{(AD+BC)\frac{V_O^2}{Z_i} + ACV_O^2 + BD\frac{V_O^2}{Z_i^2}} \tag{3}$$

$$= \frac{Z_i}{(AD+BC)Z_i + ACZ_i^2 + BD}$$

$$= \frac{Z_i}{\gamma_1 \cdot Z_i + \gamma_2 \cdot Z_i^2 + \gamma_3}$$

# Network model

Generally, $\gamma_i$ are complex so $\gamma_i = \gamma_{i,\mathrm{Re}} + j \cdot \gamma_{i,\mathrm{Im}}$. Expanding it, we have

$$\frac{S_O}{S_I} = PR_R + j \cdot PR_I$$
$$= \frac{Z_i^2 \cdot \gamma_{1,\mathrm{Re}} + Z_i^3 \cdot \gamma_{2,\mathrm{Re}} + Z_i \cdot \gamma_{2,\mathrm{Re}}}{b_1 + b_2} - j \cdot \frac{Z_i^2 \cdot \gamma_{1,\mathrm{Im}} + Z_i^3 \cdot \gamma_{2,\mathrm{Im}} + Z_i \cdot \gamma_{2,\mathrm{Im}}}{b_1 + b_2} \quad (4)$$

where

$$b_1 = \left(Z_i \cdot \gamma_{1,\mathrm{Re}} + Z_i^2 \cdot \gamma_{2,\mathrm{Re}} + \gamma_{3,\mathrm{Re}}\right)^2$$
$$b_2 = \left(Z_i \cdot \gamma_{1,\mathrm{Im}} + Z_i^2 \cdot \gamma_{2,\mathrm{Im}} + \gamma_{3,\mathrm{Im}}\right)^2$$

# Numerical optimization

The objective function is

$$f(x) = \frac{ax^2 + bx^3 + cx}{(ax + bx^2 + c)^2 + (Ax + Bx^2 + C)^2}$$

where, the only variable is $x$, $x$ belongs to real number and $x$ >0; other six parameters are constants.

Our goal is that for maximizing above function, we seek an optimization solution $x^*$. This requirement can be met when the first-order derivative of function $f(x)$ equal to 0, i.e.

$$f'(x^*) = 0$$

# Numerical optimization

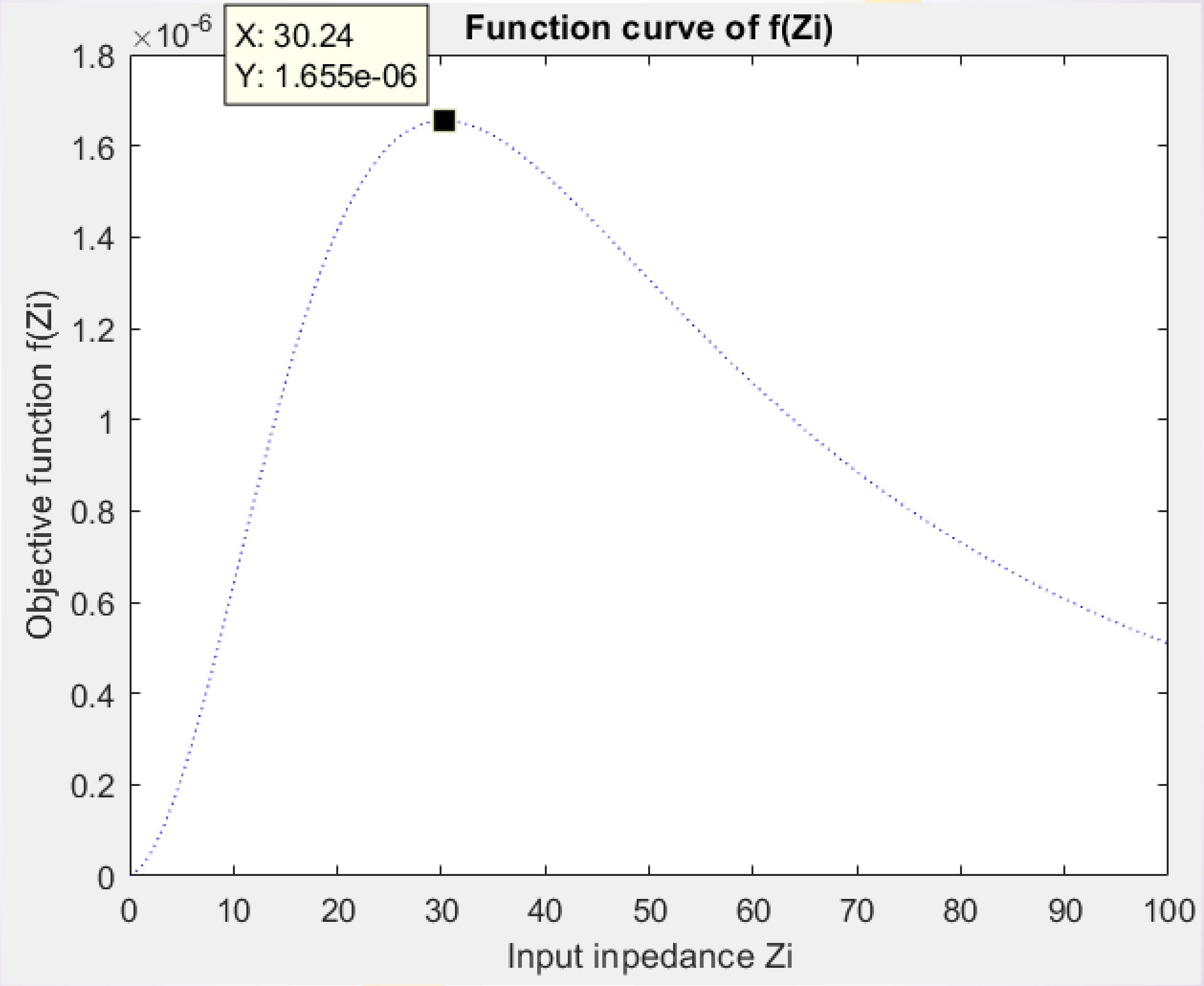



Figure: Plot of f demonstrating the global maximum of the function.

# Simulation results

Assuming, we have a typical power signal (at 60 Hz) and multiplex it with a data signal as follows

$$V_S(t) = 120 \cdot \sqrt{2} \cdot \cos(377t) + v_d(t)\cos(2\pi \cdot 1000t)$$

where

$$v_d(t) = \begin{cases} 12; \text{ if } v_d(n \cdot t) = 12 \text{ and } (n \cdot \Delta t \leq t \leq (n+1)\Delta t) \\ 0. \text{ otherwise} \end{cases}$$

That is, $v_d$ function is a continuous function constructed from a sequence of scaled discrete pulses with duration $t$ and occurring at steps $n \cdot \Delta t$ with.

# Simulation results

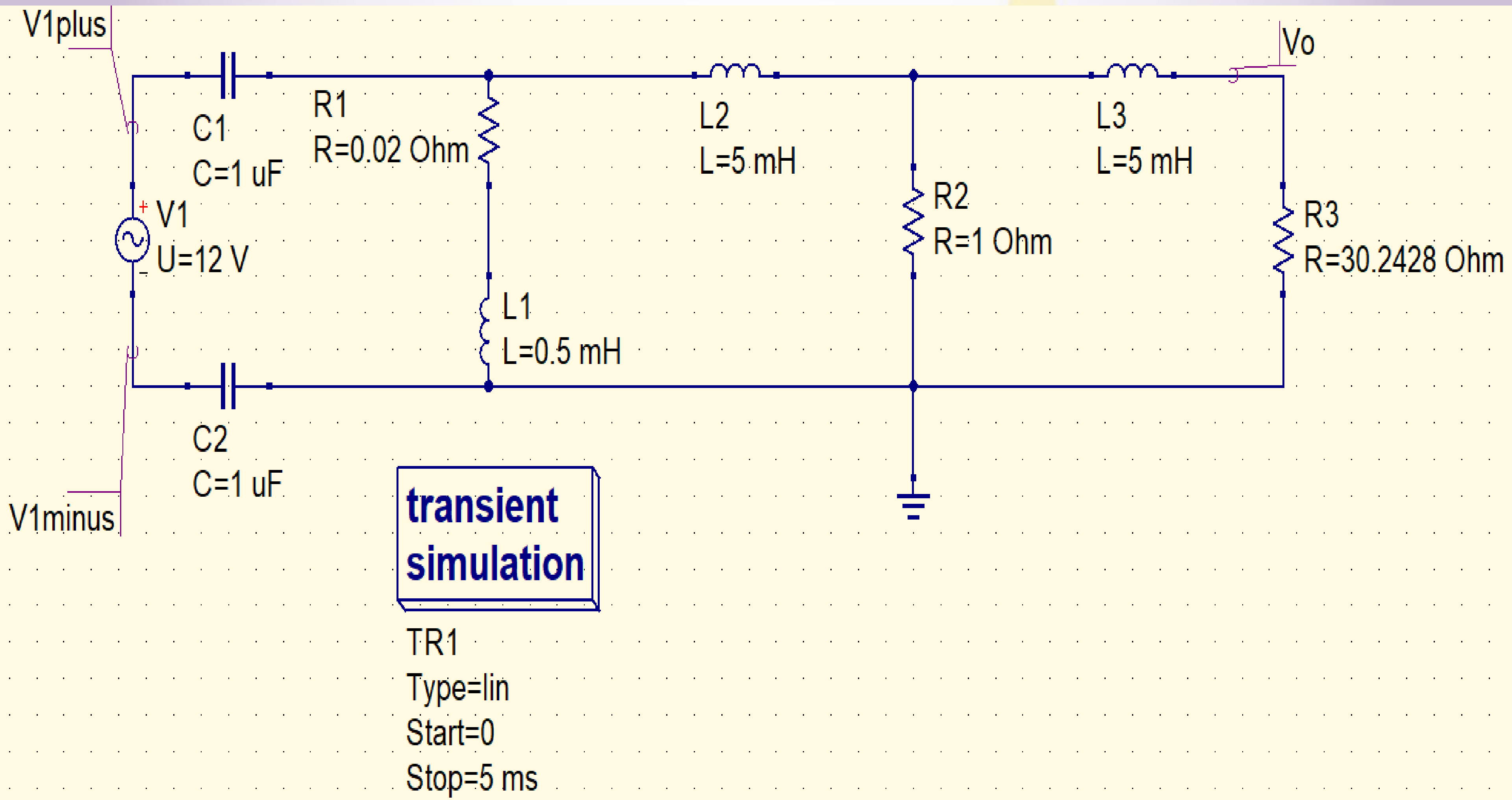



Figure: The diagram of circuit simulation.

# Simulation results

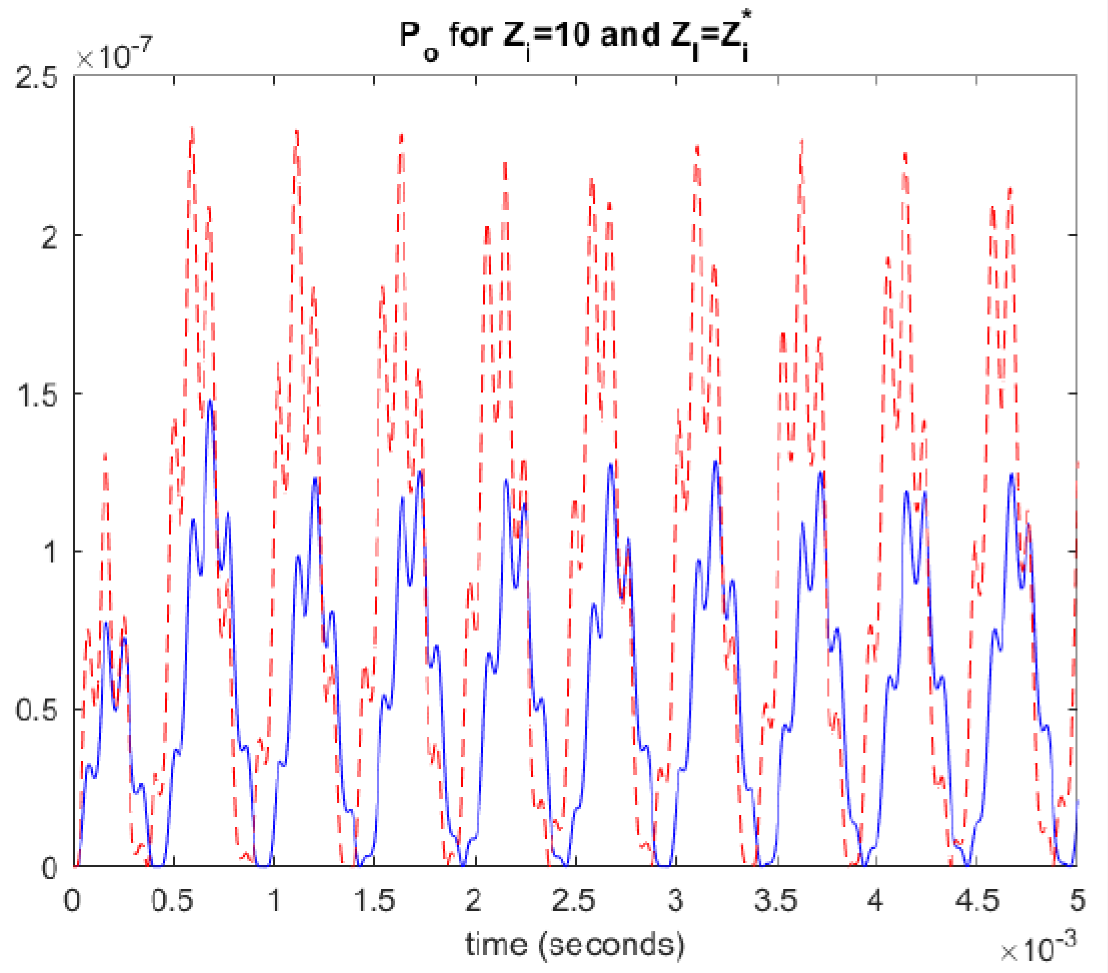



Figure: Po with Zi = 10 for the solid curve and Zi = Zi* for the dashed curve.

# Conclusions

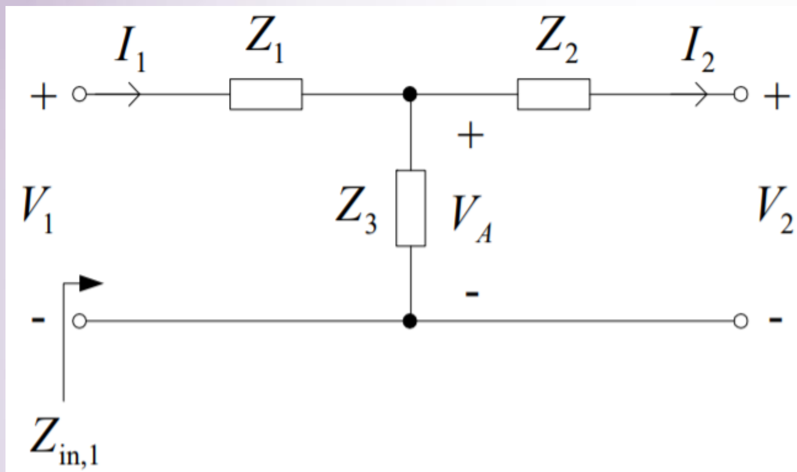
We presented a methodology to optimize signal power transfer through a PLC network.

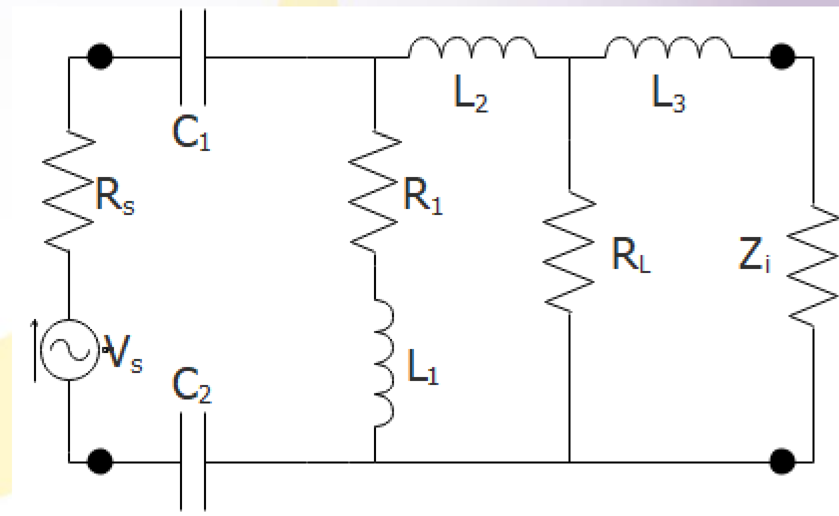
Input impedance can be adjusted at the receiver end of the network in response to feeder load changes between the transmission side and receiver side.

We expected this methodology can be used at where feeder loads are measureable and can be reported in near real-time to the receiver end of the network.

# Thank you for your listening!

# Q&A_1 How to get the ABCD



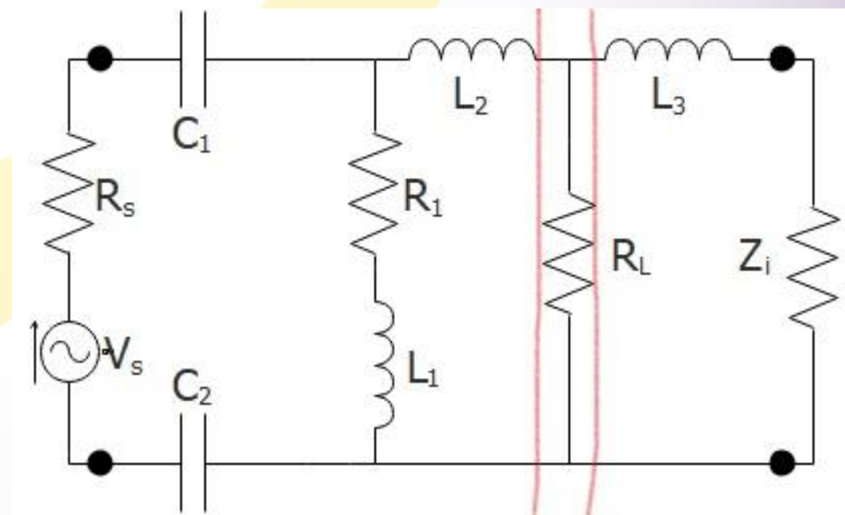




$$A = 1 + \frac{Z_1}{Z_3}$$

$$B = Z_1 + Z_2 + \frac{Z_1 Z_2}{Z_3}$$

$$C = \frac{1}{Z_3}$$

$$D = 1 + \frac{Z_2}{Z_3}$$



# Q&A_2 The minus sign in Equation (4)

Based on

$$\frac{a}{b + j \cdot c} = \frac{a \cdot (b - j \cdot c)}{(b + j \cdot c) \cdot (b - j \cdot c)}$$
$$= \frac{ab}{b^2 + c^2} - j \cdot \frac{ac}{b^2 + c^2}$$

We have

$$\frac{S_O}{S_I} = \frac{Z_i}{\gamma_1 \cdot Z_i + \gamma_2 \cdot Z_i^2 + \gamma_3}$$
$$= \frac{Z_i^2 \cdot \gamma_{1,\mathrm{Re}} + Z_i^3 \cdot \gamma_{2,\mathrm{Re}} + Z_i \cdot \gamma_{2,\mathrm{Re}}}{b_1 + b_2} - j \cdot \frac{Z_i^2 \cdot \gamma_{1,\mathrm{Im}} + Z_i^3 \cdot \gamma_{2,\mathrm{Im}} + Z_i \cdot \gamma_{2,\mathrm{Im}}}{b_1 + b_2}$$

# Q&A_3 The final power transfer expression

$$\frac{S_O}{S_I} = \frac{P_O + jQ_O}{P_I + jQ_I}$$

$$= \frac{(P_O + jQ_O)(P_I - jQ_I)}{(P_I + jQ_I)(P_I - jQ_I)}$$

$$= \frac{P_O P_I + Q_O Q_I}{P_I^{\,2} + Q_I^{\,2}} - j\,\frac{P_O Q_I - Q_O P_I}{P_I^{\,2} + Q_I^{\,2}}$$

When QI & QO is small enough, the real part of power transfer function is equal to active power ratio.