Toward Unified Modeling for Future Energy Systems and Efficiency Measures

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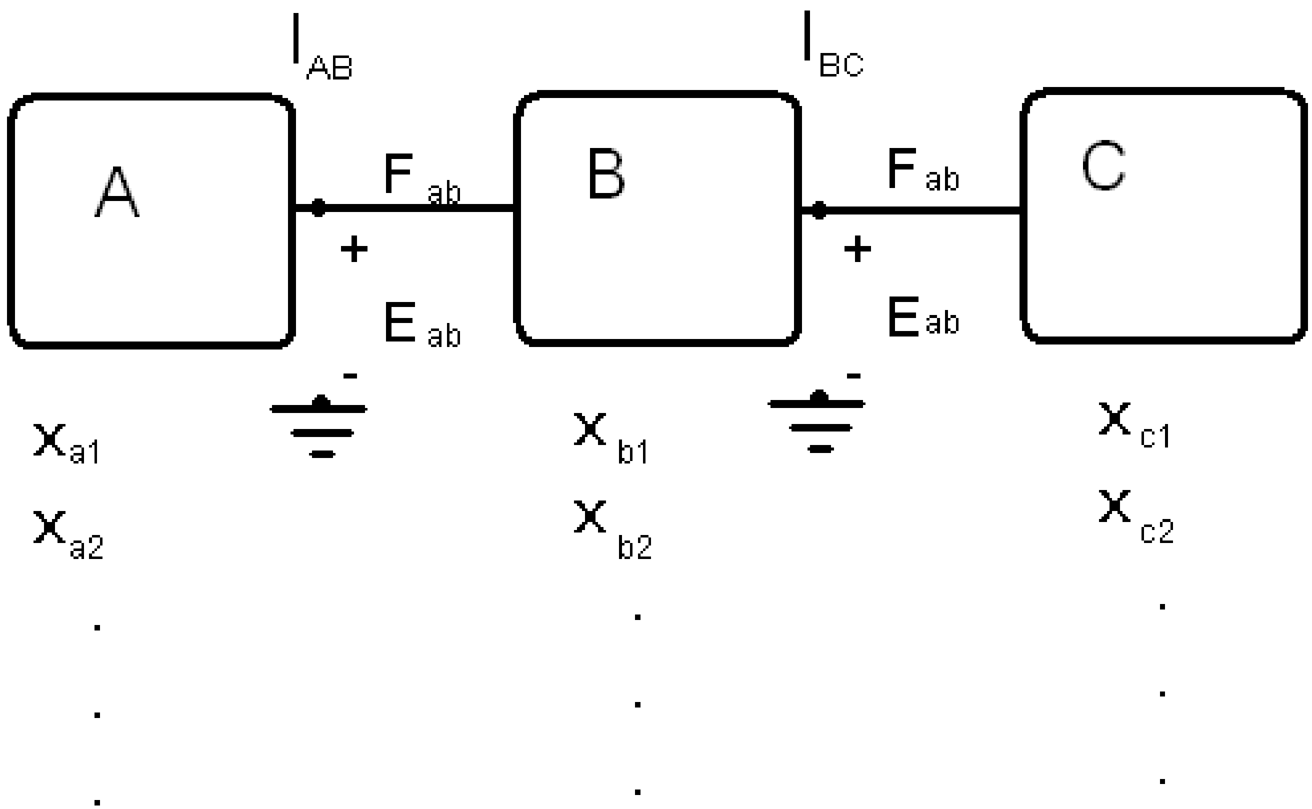
Motivation

- Future energy systems combine various energy conversion processes together (chemical, mechanical, thermal, etc.)
- Delivery of power essential to any system, regardless of its nature
- System dynamics as well as steady state dynamics included in the module based model

Module Based Representation of an Energy system



E = Cross Variable, F = Through Variable
i.e. E = Voltage and F = Current in electricity

General Model of a Module

$dx_i/dt = f(x_i, u_i, I_i)$

$I_i = g_i(x_{i-})$

$dI_i/dt = d(g_i(x_{i-}))/dt$

$dI_i/dt = d(x_{i-})/dt * (d(g_i(x_{i-}))/d(x_{i-}) -)$

- Each module contains its own local variables.
- The interaction variable would be a function of its neighboring local variables.

The local and interaction variables all have their own dynamics

Choice of Interaction Variables

- Candidates for Interaction variable
- Power or Energy : physical importance
- Instantaneous power can be separated into its real and reactive power components
- In all physical systems, transfer of energy (power) is key to the system's operation, regardless of the type
- Delivering power to accomplish a task is
oal of any man-made syst

Choice of Interaction Variables

- E(t) = Cross Variable, F(t) = Through Variable
  - i.e. E(t) = Voltage and F(t) = Current, in electricity

Real Power

$P(t) = E(t)*F(t)$

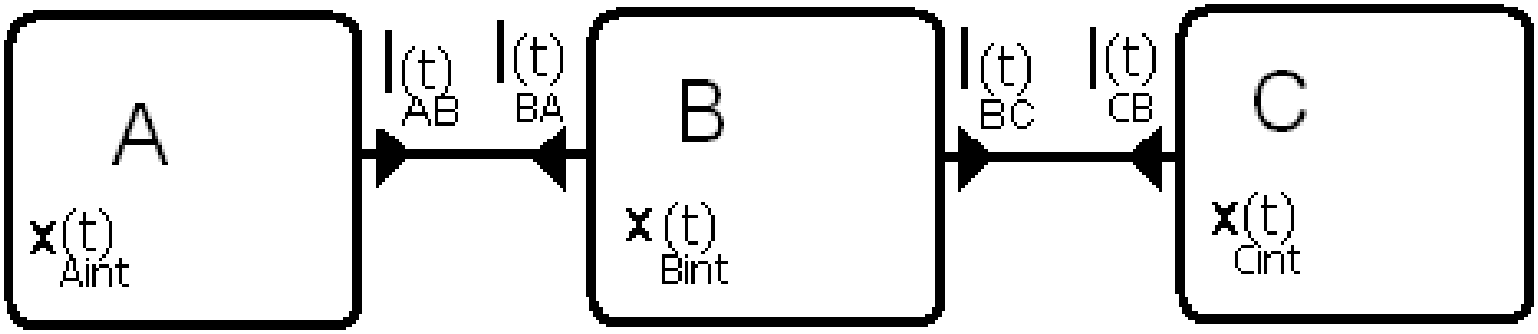
ref: Paynter

Reactive Power

$Q(t) = E(t)*(dF/dt) – F(t)*(dE/dt)$

ref: Wyatt, Ilic

Module Based System Model



-Extended state space model (internal and interaction state variables)

-A mathematical model of the interconnected system in terms of ODEs (not DAEs), creating a nonlinear system of ODEs for components in terms of their internal and interaction variables.

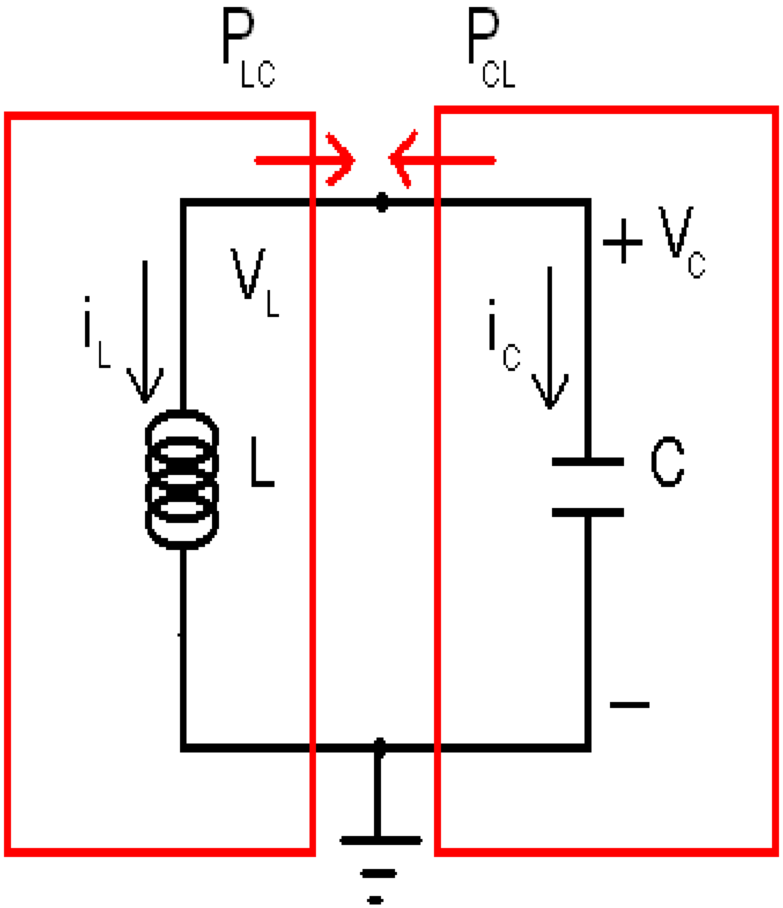
Note: Conventional nonlinear energy transfer models are DAEs (internal) dynamics subject to algebraic network constraints)

General Structure of the Mathematical Model

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \vdots \\ \dot{x}_n \end{bmatrix} = \begin{bmatrix} f_1(x_1(t), I_1(t)) \\ f_2(x_2(t), I_2(t)) \\ \vdots \\ f_n(x_n(t), I_n(t)) \end{bmatrix} \qquad \begin{bmatrix} \dot{I}_1 \\ \dot{I}_2 \\ \vdots \\ \dot{I}_m \end{bmatrix} = \begin{bmatrix} g_1(x_1^-(t)) \\ g_2(x_2^-(t)) \\ \vdots \\ g_m(x_m^-(t)) \end{bmatrix}$$

Let $x_i^-(t)$ represent the internal state variables of all the neighboring modules to I_i

Simple Example



Component 1: Inductor

internal state variable: i_L

$di_L/dt = (1/L)*(P_{LC}/i_L)$

Coupling Variables:

P_{LC} Q_{LC}

Simple Example, continued

Component 2: Capacitor

internal state variable: v_C

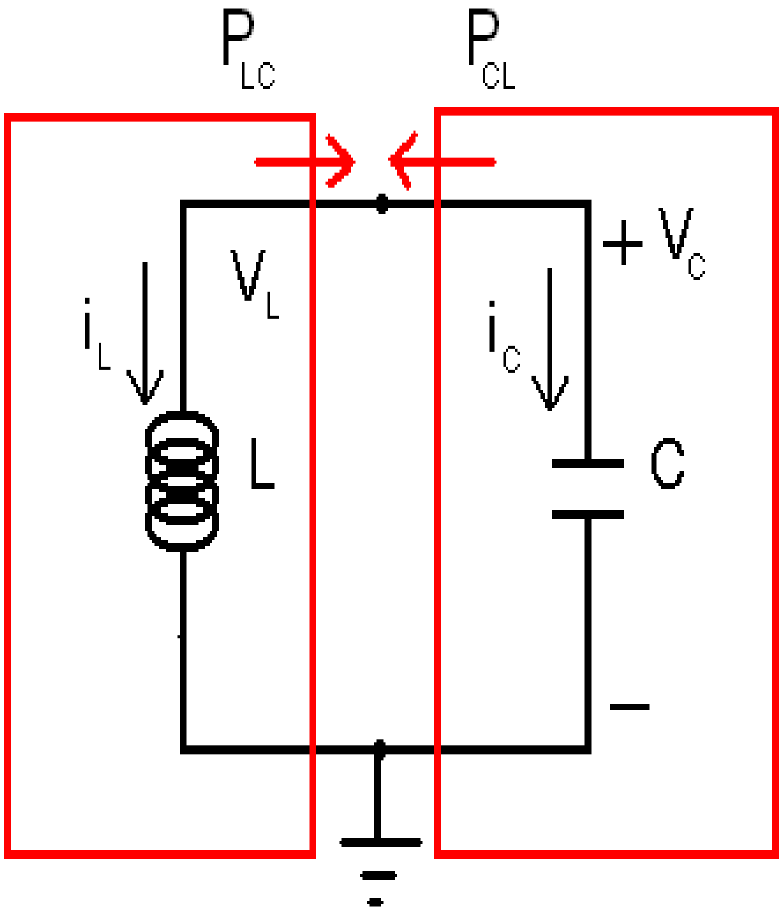
$dv_C/dt = (1/C)*(P_{LC}/v_C)$

Coupling Variables:

P_{CL} Q_{CL}

Subject to:

$P_{CL} = -P_{LC}$ $Q_{CL} = -Q_{LC}$



Conclusions

- Novel modeling approach is needed for future energy systems with mixed energy conversion processes (e.g. chemical, mechanical, thermal)
- Choice of interaction variables determines the complexity and structure of the system
- Module based modeling approach lends itself to distributed monitoring and decision making
- Future work – interpret system efficiency and reliability in terms of component properties

References

Wyatt, J., and M. Ilic, "Time-Domain Reactive Power Concepts for Nonlinear, Nonsinusoidal or Nonperiodic Network," IEEE International Symposium on Circuits and Systems, Volume 1 , Issue 3, May 1990 Page(s): 387 – 390

Paynter, Henry M. "Analysis and Design of Engineering Systems." Cambridge, MA: The M.I.T. Press, 1960