Real Time Digital Simulation of Electric Power Systems

Yi Zhang
RTDS Technologies Inc.
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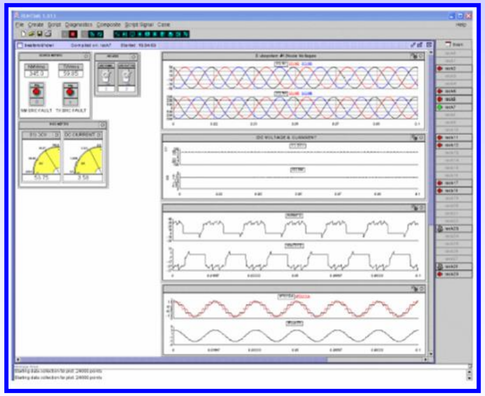
Real Time Digital Simulation of HVDC Systems

Presentation Outline

- **Theory of Parallel Computation for Power Systems**
- **Overall Introduction of Real Time Simulation**
- **The Solution Structure of Real Time Simulation: Parallel Processing**
- **Differences between Real Time and Non Real Time Simulation**
  - **No Interpolation**
  - **No Iteration**
  - **Model Simplification**
  - **Small Time Step Solution**
  - **Surrogate Network**

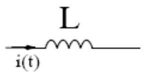


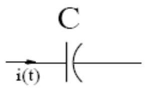
- **Questions and Answers**

EMT Theory

Real Time Digital Simulation

- Electromagnetic transient solution (EMTP type simulation)
  - Based on the *Dommel* algorithm
  - Trapezoidal rule of integration
  - New solution produced each timestep



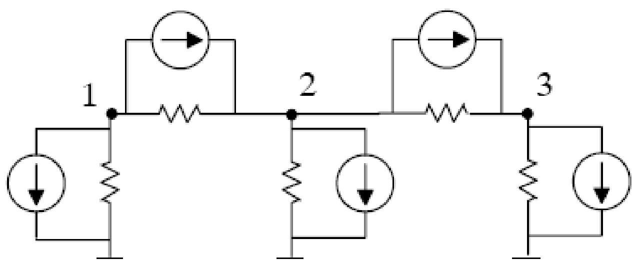


$$v(t) = L * \frac{d\,i(t)}{dt} \qquad i(t) = C * \frac{d\,v(t)}{dt}$$

$$i(t) = \frac{1}{L}\int v(t)\,dt \qquad v(t) = \frac{1}{C}\int i(t)\,dt$$

applying trapezoidal rule of integration

$$i(t) = \frac{\Delta t}{2L}\,v(t) + I_h(t-\Delta t) \qquad i(t) = \frac{2C}{\Delta t}\,v(t) - I_h(t-\Delta t)$$



$$\begin{bmatrix} V1 \\ V2 \\ V3 \end{bmatrix} = \begin{bmatrix} G11 & G12 & G13 \\ G21 & G22 & G23 \\ G31 & G32 & G33 \end{bmatrix}^{-1} \begin{bmatrix} I1 \\ I2 \\ I3 \end{bmatrix}$$

Simulation Hardware

A Rack:

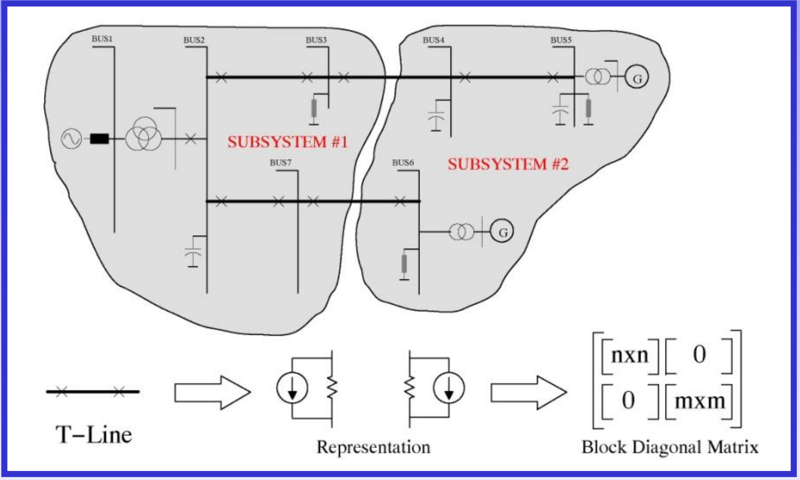
A unit of hardware is called a ‘*Rack*’ and typically includes:

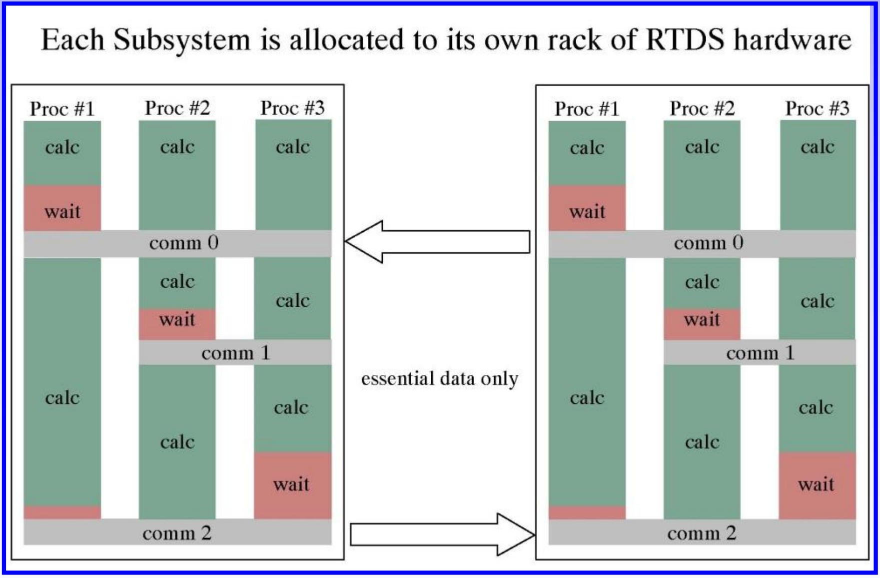
- 1~6 RISC Processor Card (PB5)
- 1 Giga Transceiver Workstation InterFace Card (GTWIF)

Network Splitting

Splitting the Network into Subsystems:

As the network gets bigger the size of the conductance matrix also increases (one matrix element per system node).





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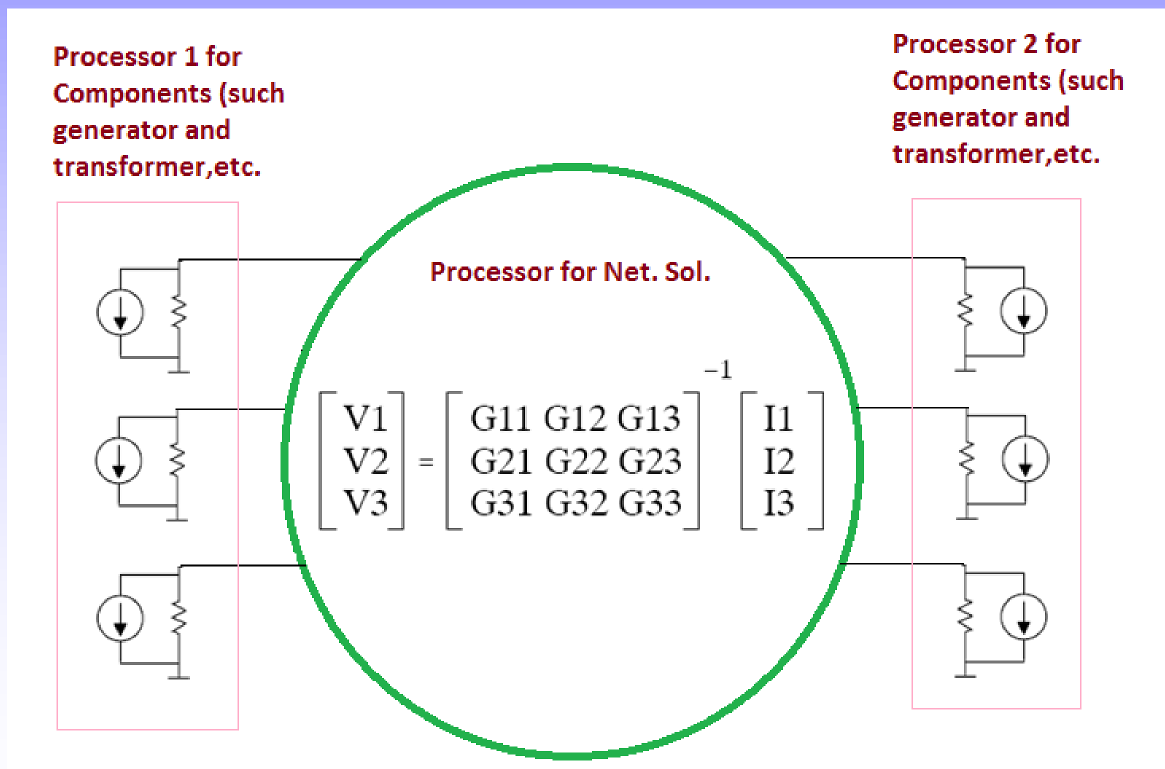
Solution Structure

Balance between Efficiency and Flexibility:

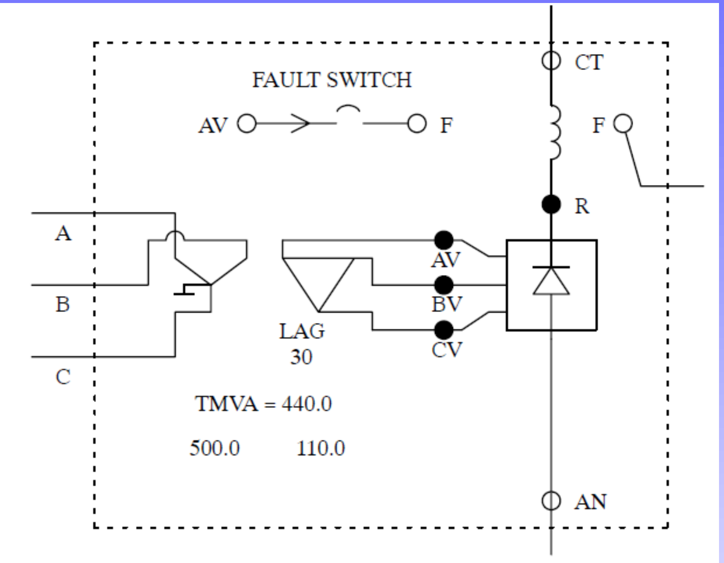
One of Two Processors Per Rack Exclusively Used for Network Solution

Other Processors Used for Component



Power System Components

An Example:
Six Pulse Valve Group Model in RTDS



- Embedded Model
- With internal faults included
- Improved firing function
- Be used and verified for over 10 years
- Developed based on close relationship with world leading manufactures

External Nodes vs Internal Nodes

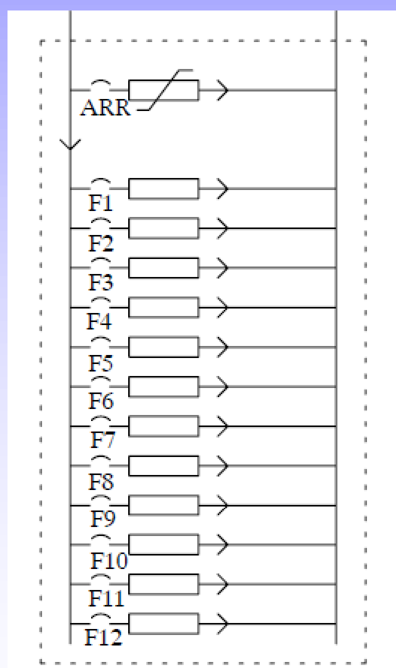
- External nodes connect the network solution
- Internal nodes be eliminated
- The purpose is to minimize the number of nodes

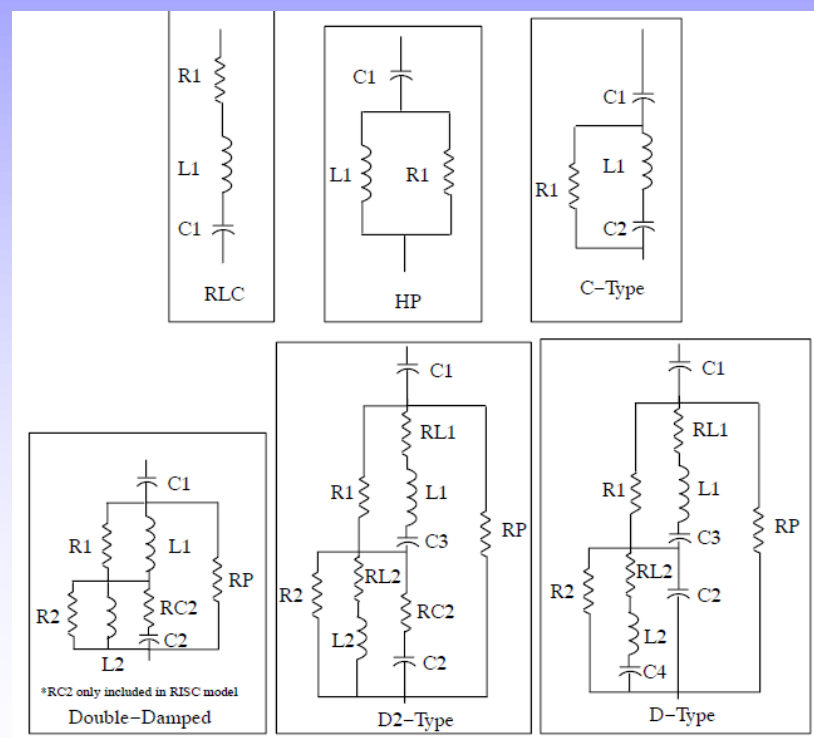
Power System Components

Other Example: Switchable Filter

Modelling filters in individual branch requires significant resources

- Switchable filter model can represent 12 filter plus 1 arrestor on 1/12 processor
- Various types of filters are included according to the requirement of manufactures





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Solution Requirements

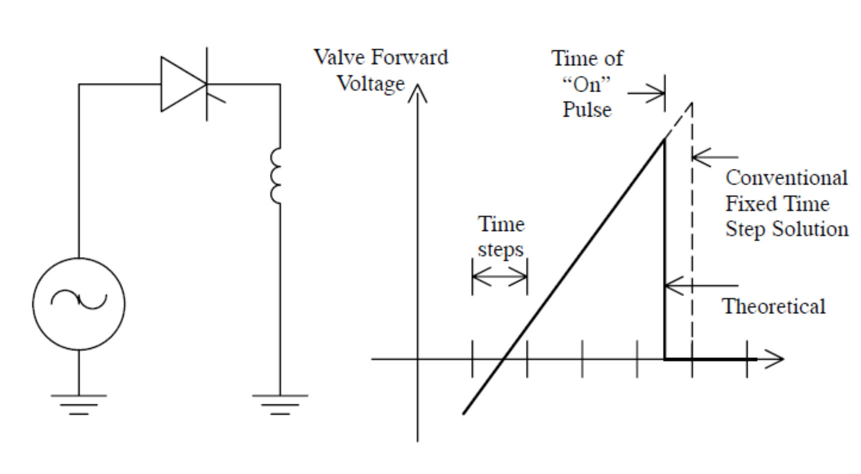
No Interpolation and No Iteration are allowed

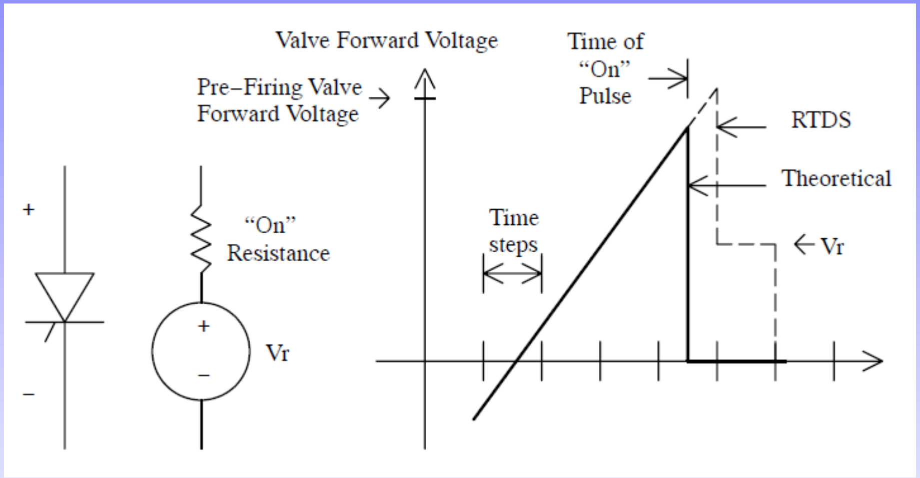
- The time step in real time simulation must be strictly predictable
- The longest predicted time step should be less than the time step used
- Interpolation is not possible because the firing pulse may come at the last moment within a time step, therefore no sufficient time available for interpolation
- Iteration is not possible either because the convergent cannot be guaranteed with certain times of the iteration, therefore the time step cannot be predicted.
- Alternative approaches must be taken to deal with the valve On/Off and nonlinearity within some components

Modelling of HVDC Valve

Improved Firing – An Important Aspect of Digital Simulation

The Algorithm of Improved Firing





- Compensation through improved firing function instead of interpolation
- Even delay exists but possible to be adjusted
- Successfully avoid non-characteristic harmonics due to numerical jitters
- Implemented in software-hardware special design
- Same idea in creating valve current zero crossing pulse

Modelling of HVDC Valve

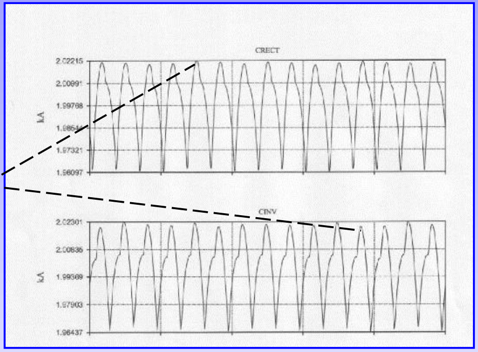
Improved Firing – An Important Aspect of Digital Simulation

- The Effect of Improved Firing

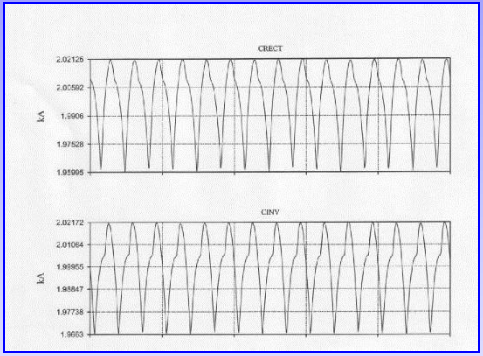
Idc Rectifier

Firing Pulse Jitter

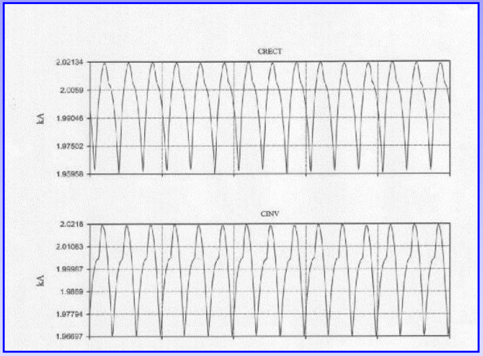
Idc Inverter



- Δt = 10 μsec
- No Improved Firing



- Δt = 50 μsec
- With Improved Firing

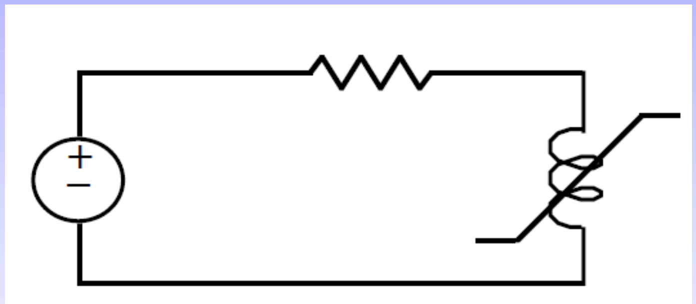


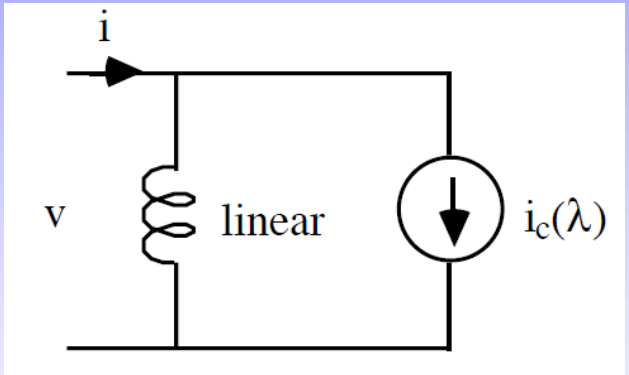
- Δt = 65 μsec
- With Improved Firing

Modelling of Nonlinear Components

Example: Saturation Curve in Transformers

- *Variable G vs Injection Model*
- *Prediction and Correct Method*
- *Numerical Damping*





Modelling of Nonlinear Components

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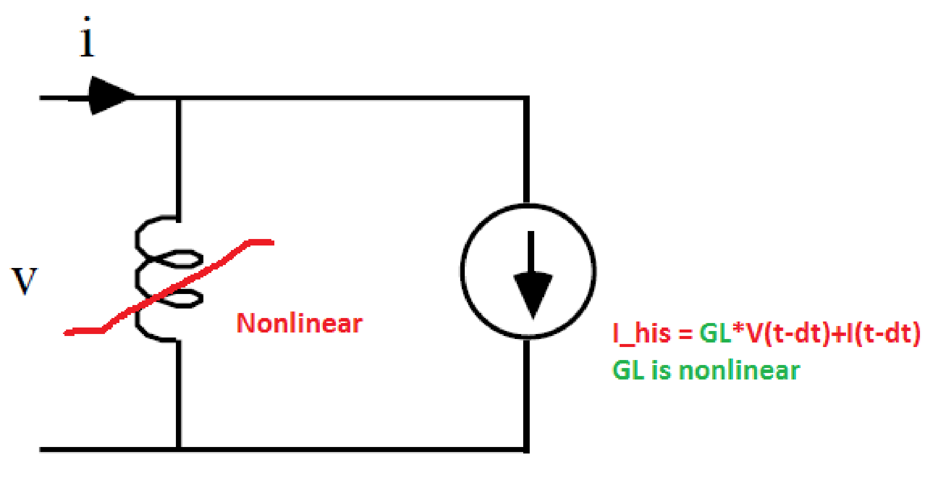

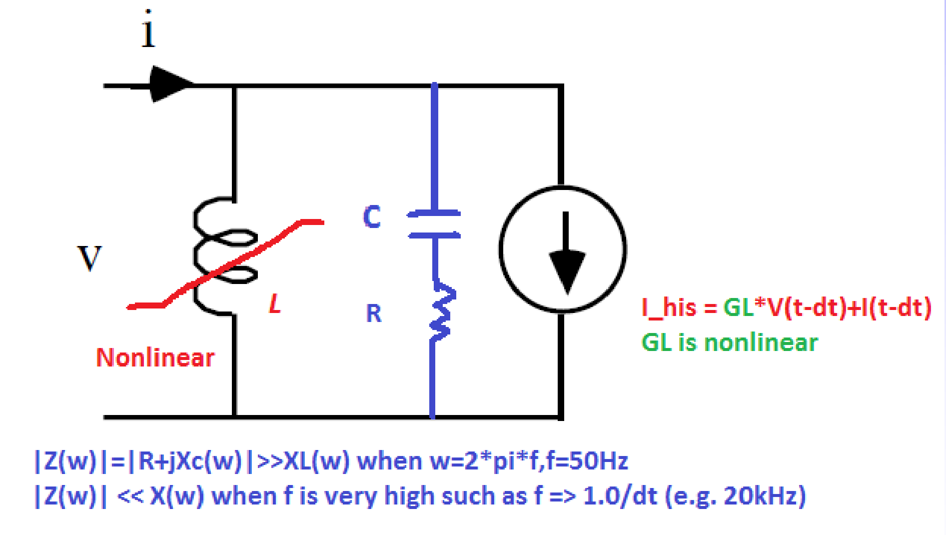

Modeling of TLINE and Cable in Small Time Step

FREQUENCY DEPENDENT PI SECTION

➢***The frequency dependent TLINE/Cable model cannot be used in small time step solution, because the high computation burden of convolution is not permitted in small time step;***

➢***This model provide a frequency-dependent representation of a single-phase transmission line or cable;***

➢***Each instance of the PI model can optionally represent between 1 and 4 identical single-phase series-connected PI sections and the intermediate nodes.***

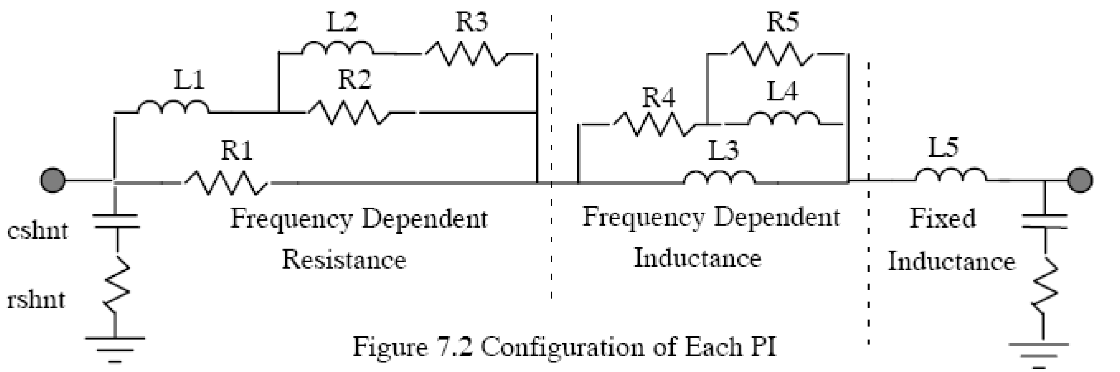

Figure 7.2 Configuration of Each PI

Modeling of TLINE and Cable in Small Time Step

Frequency Dependent PI Section Model

- **Fitting the frequency dependent characteristic of resistor-**

$$Z_R(\omega) = \cfrac{R_1}{1 + \cfrac{\cfrac{R_1}{j\omega L_1}}{1 + \cfrac{\cfrac{R_2}{j\omega L_1}}{1 + \cfrac{\cfrac{R_2}{j\omega L_2}}{1 + \cfrac{R_3}{j\omega L_2}}}}}$$

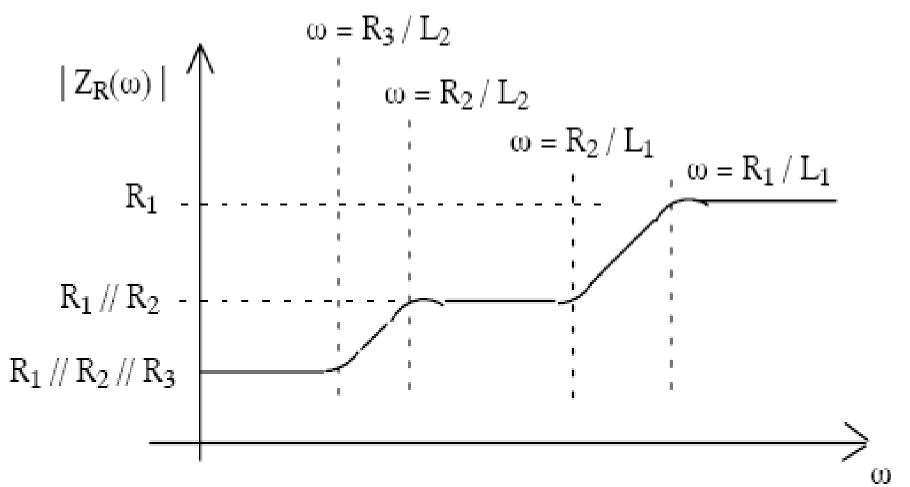

Figure 7.4 Typical Plot of Frequency Dependent Resistance

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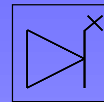
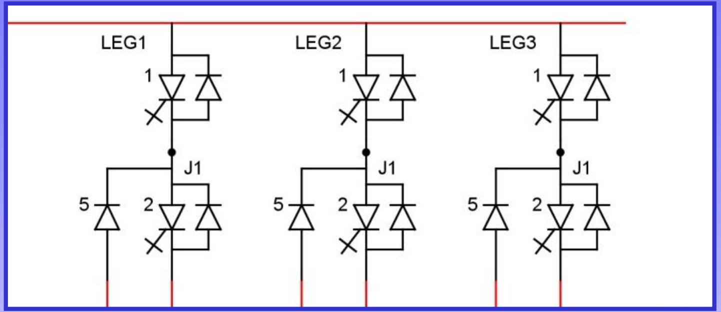
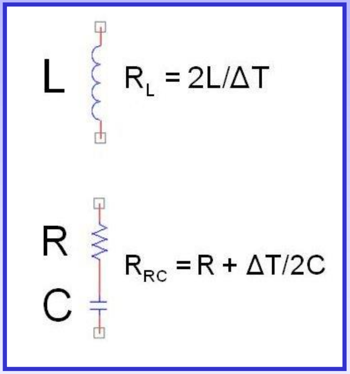
Fast VSC Simulation in Small Time Step

VSC Valve Representation



- Same branch conductance used for both the valve ON and valve OFF state
- The Dommel current history term I_H defines the valve state
- In the ON state the valve is represented as inductor
- In OFF state the vale is represented as a series RC branch
- When $R_L = R_{RC}$ then no decomposition or inversion of the VSC sub-network conductance matrix is needed when valve states are switched





ON state

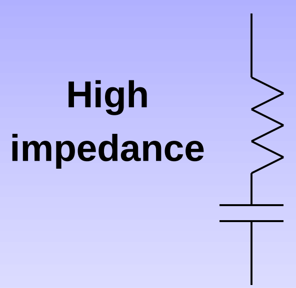
OFF state

Voltage Source Converter

Solution with constant G matrix and Small ΔT

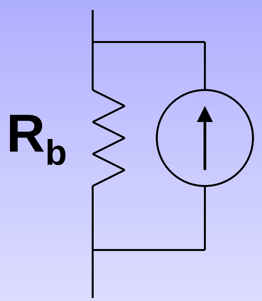
Breaker modelling

Open — **small C**

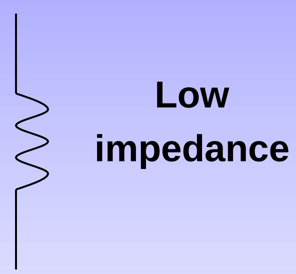


$C = \Delta T / 2R_b$

Dommel branch



Closed — **small L**



$L = R_b \Delta T / 2$

For a given C and ΔT, there is a corresponding L, which causes $\Delta T/2C = 2L/\Delta T = R_b$

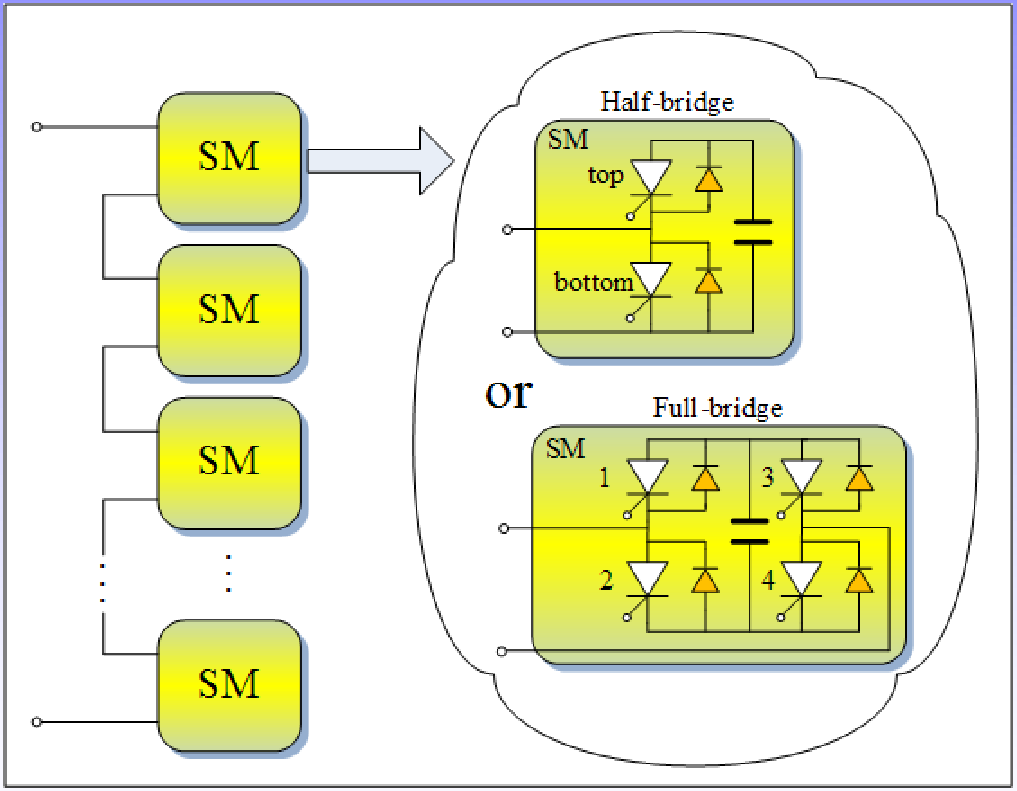
MMC Model

The Trans Bay HVDC Project:

Customer	Trans Bay Cable, LLC
Project name	Trans Bay Cable Project
Location	Pittsburg, California, and San Francisco, California
Power rating	400 MW
Voltage levels	± 200 kV DC, 230 kV /138 kV, 60 Hz
Type of plant	85 km HVDC PLUS, submarine cable
Type of semiconductor	IGBT, 212 SM per arm (1,696 per converter)

Algorithm of Real Time MMC Model

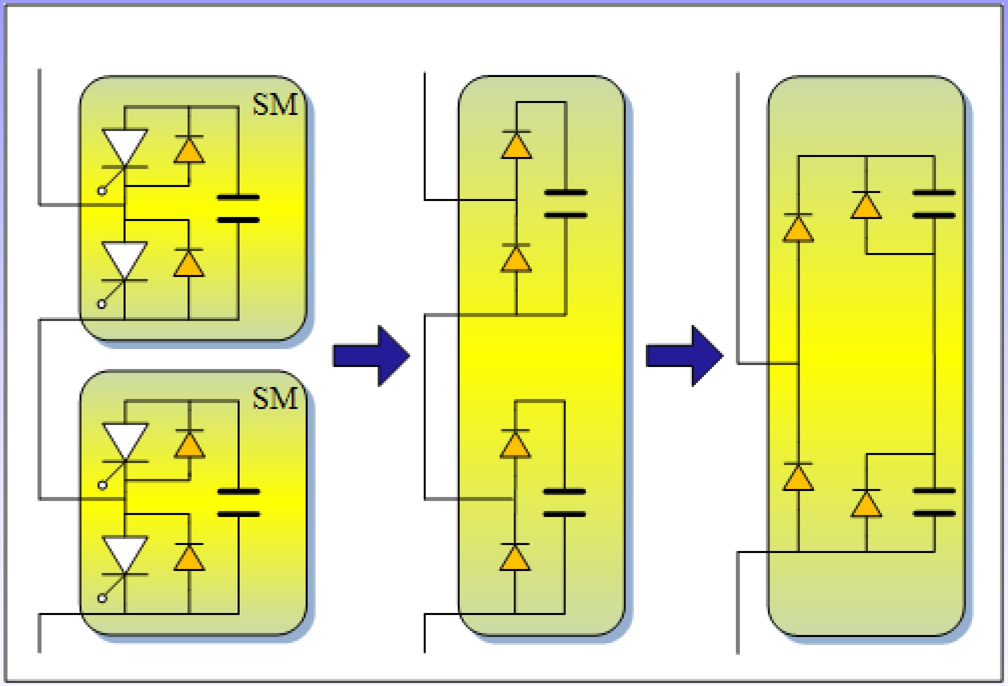
MMC Valve Model



- The calculation for MMC valve model quite heavy
- The concept of a **surrogate network** employed to reduce the computational burden
- Three configurations exist:
- Blocked
- Active Inserted
- Bypassed

Algorithm of Real Time MMC Model

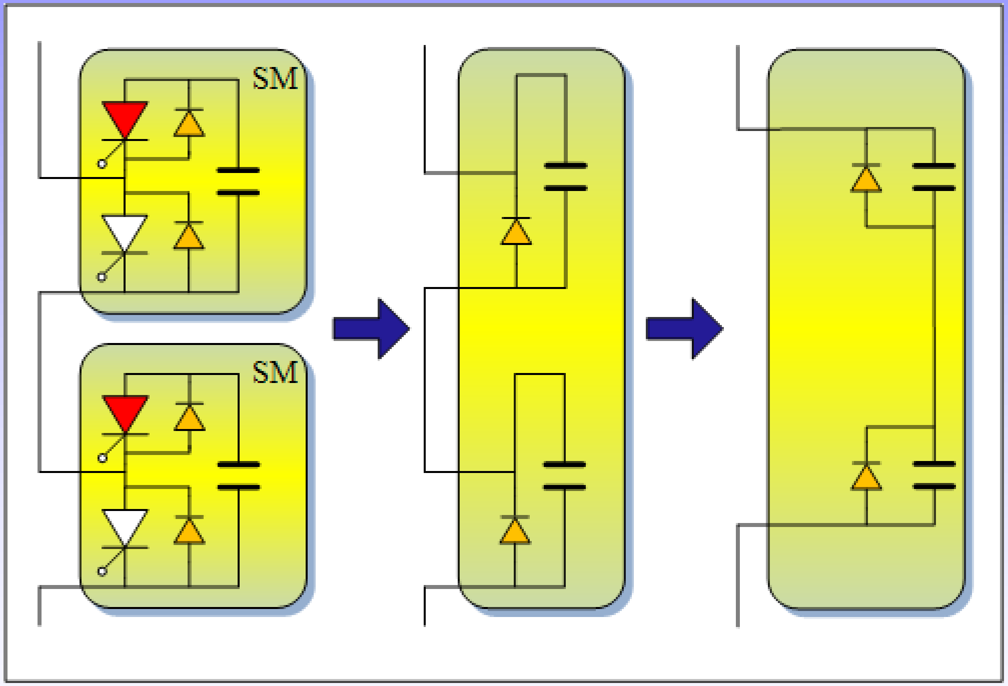
Configuration 1 - Blocked SM Model



- Neither IGBT fired
- Example of 2 SMs

Algorithm of Real Time MMC Model

Configuration 2 – Active Inserted SM Model



- The top IGBT fired
- Example of 2 SMs

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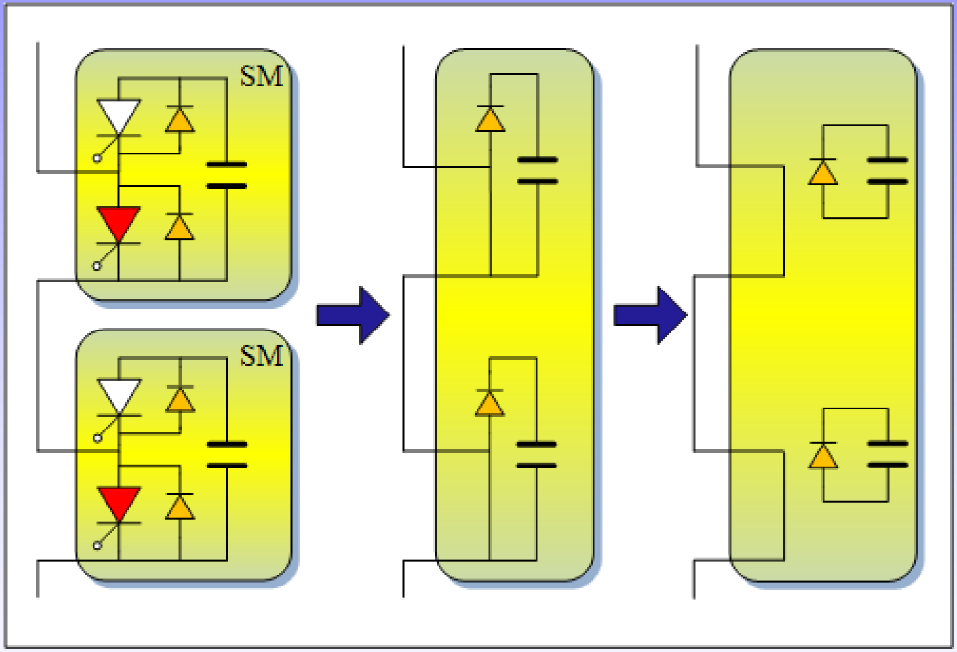
Algorithm of Real Time MMC Model

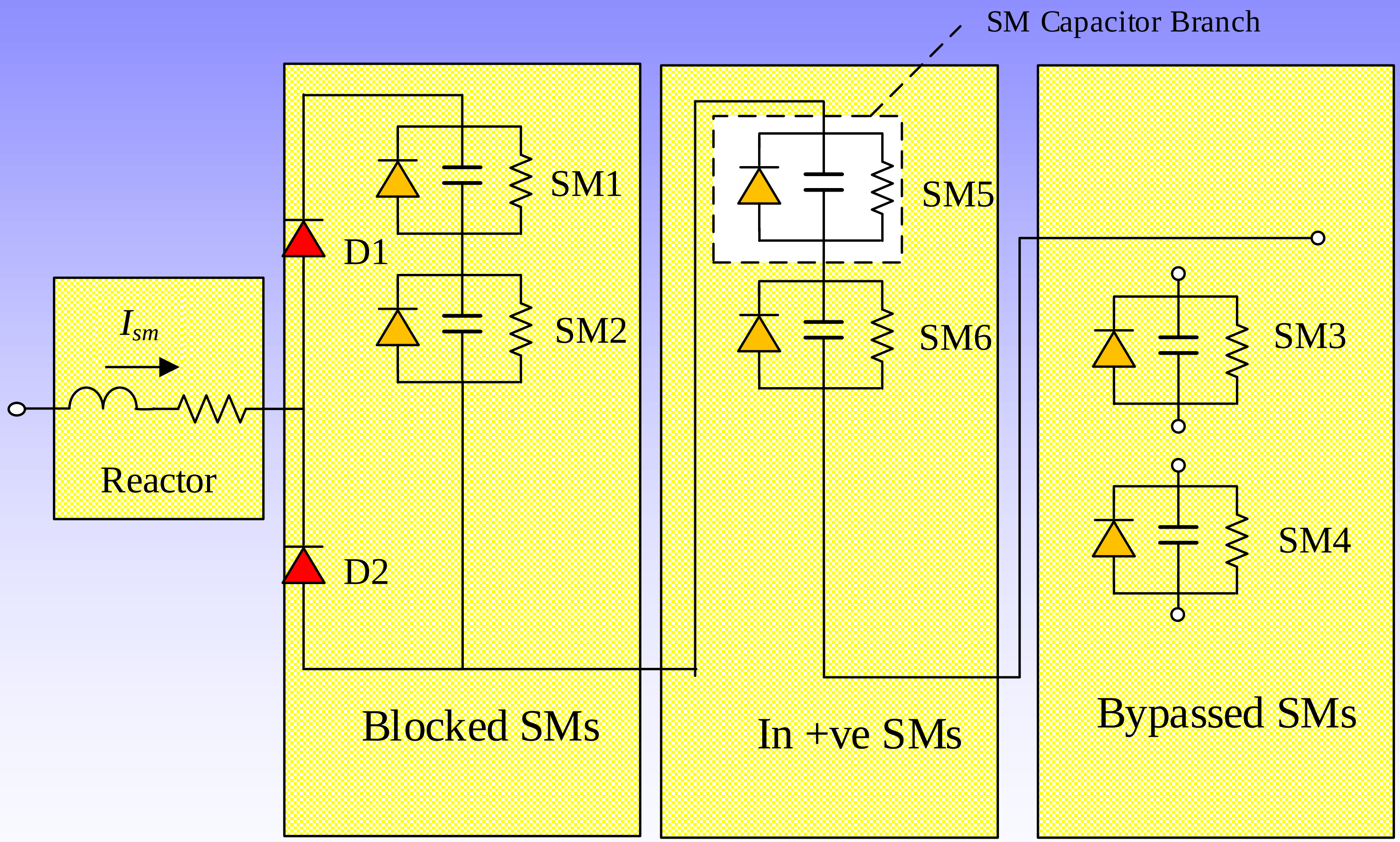
Configuration 3 - Bypassed SM Model



- Bottom IGBT fired
- Example of 2 SMs

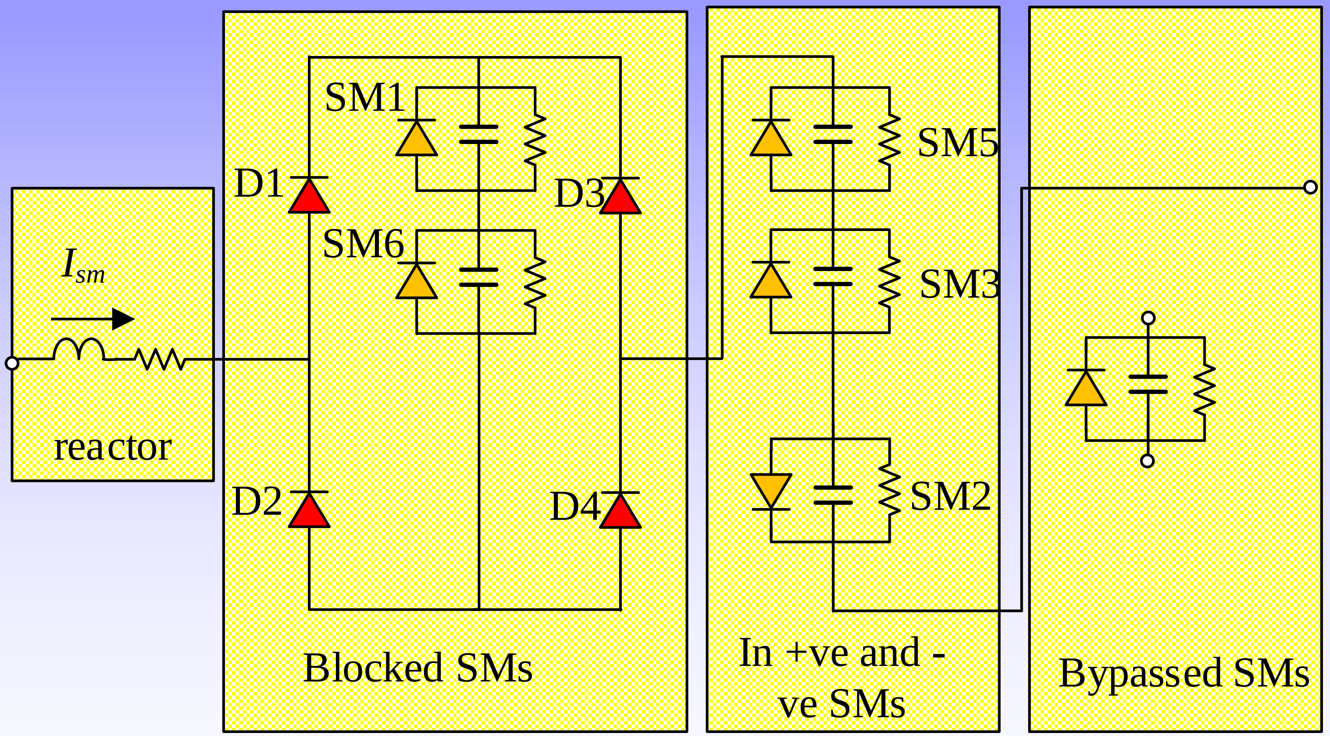
Algorithm of Real Time MMC Model

Half-Bridge Surrogate Network Topology



Algorithm of Real Time MMC Model

Full-Bridge Surrogate Network Topology



Conclusions

1. **Real Time Simulation Is Essentially A Parallel Processing EMTP**
2. **Some Specially Techniques Need to Used to Realize the Fast and Stable Solution**
3. **Questions and Answers**

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