NovaCor™

A revolution in real time.

Modeling Power Converters With User Definable Loss

RTDS Technologies

Presentation Outline

Multirate Simulation

Substep Simulation

Substep and Small Timestep

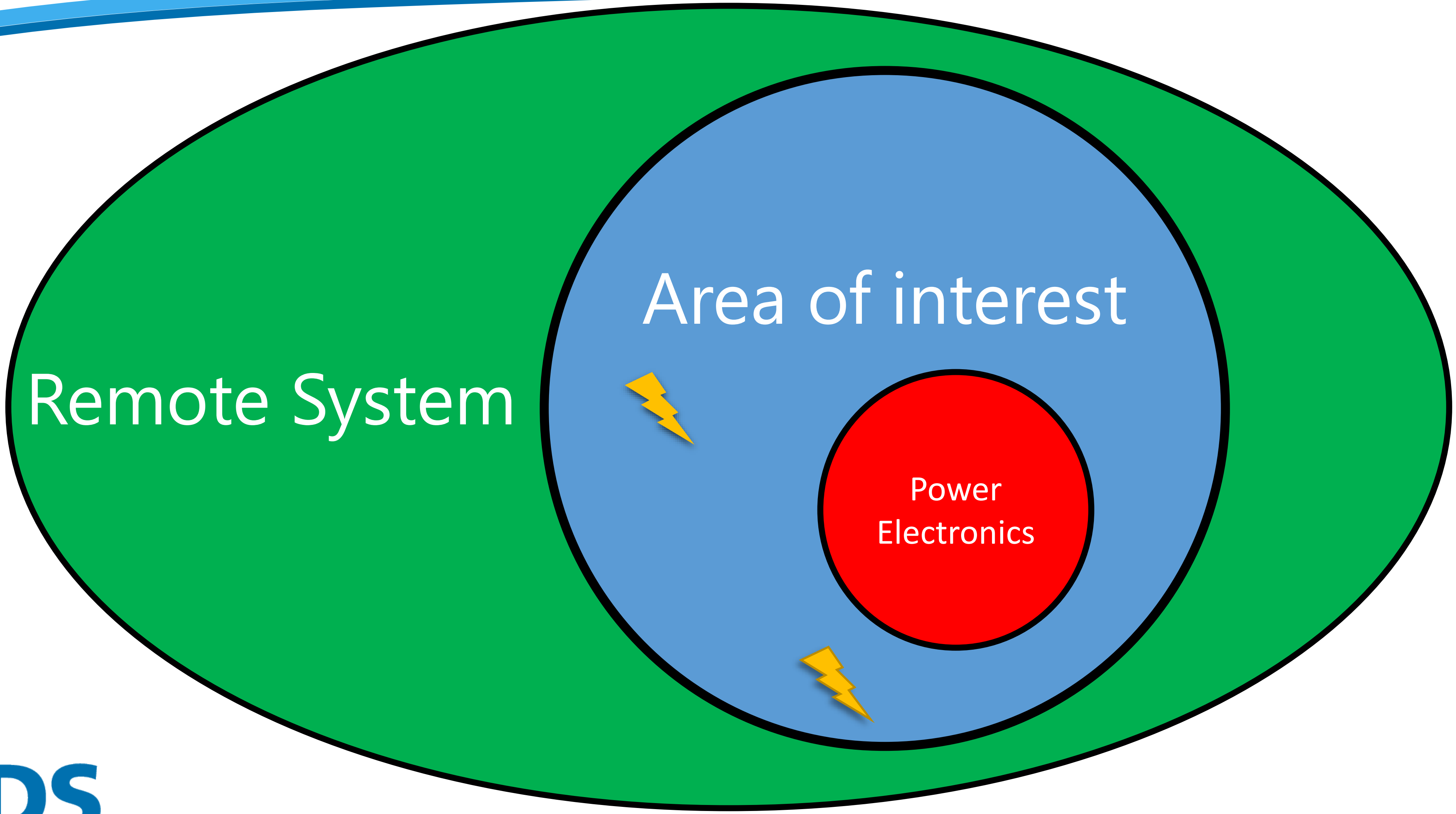
Predictive Resistive Switching Alg.

User Definable Losses

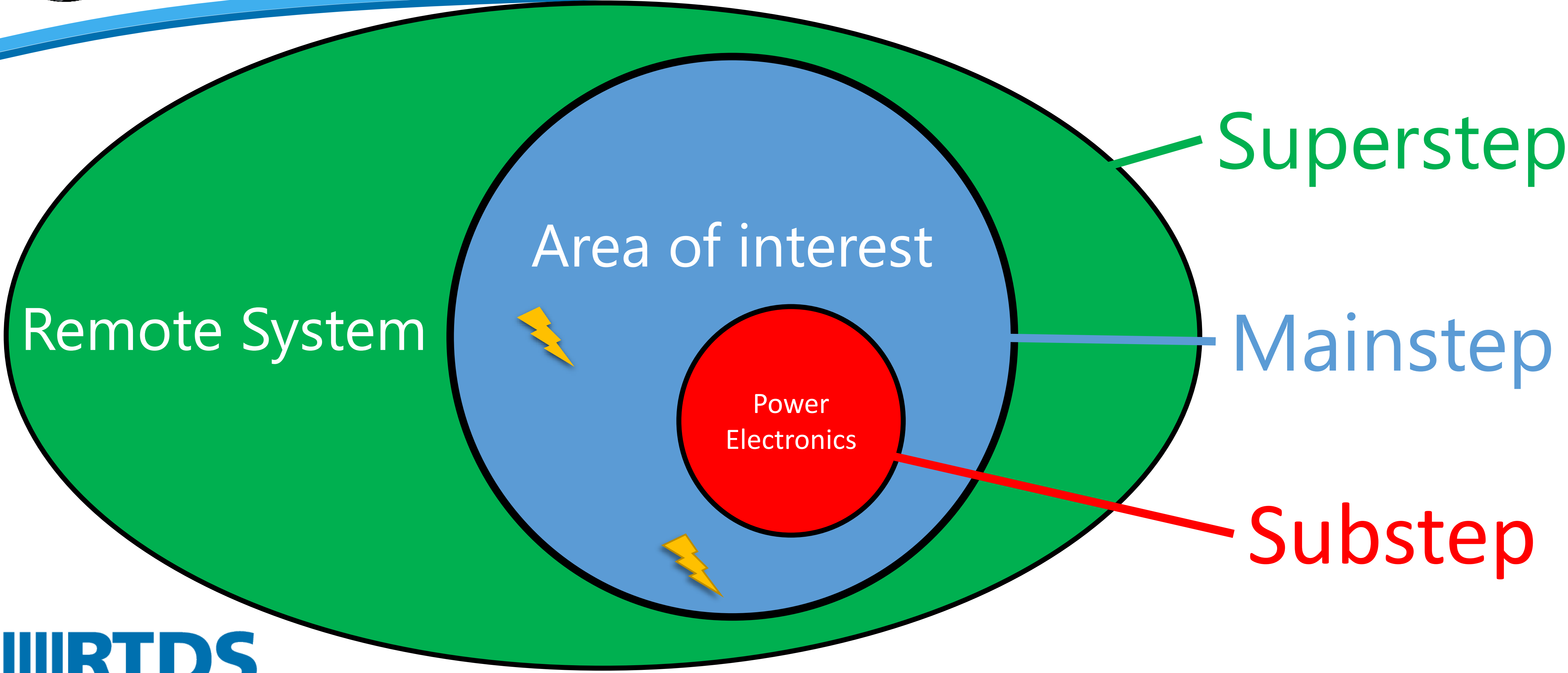
Conclusion

Other Examples

Multirate Simulation



Multirate Simulation



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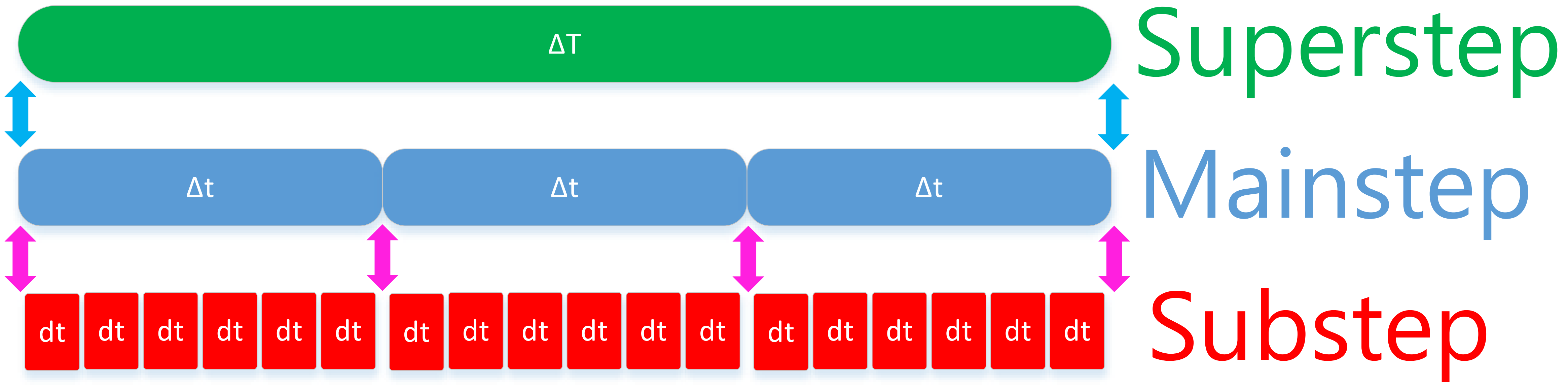
Multirate Simulation



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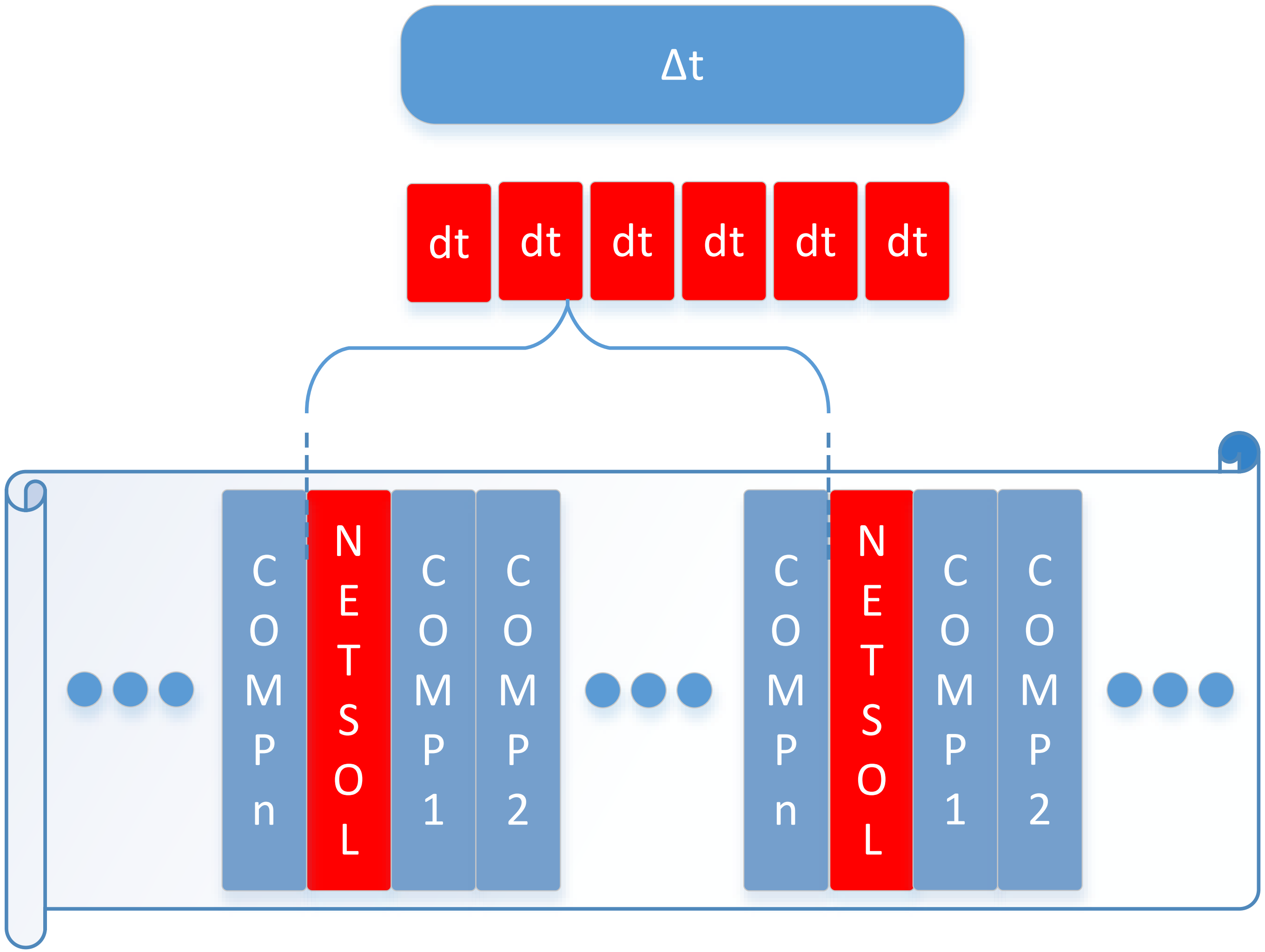
Substep


Δt
dt
dt
dt
dt
dt
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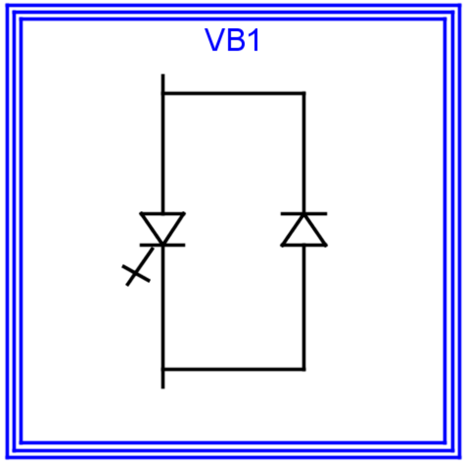
COMPn
NETSOL
COMP1
COMP2
COMPn
NETSOL
COMP1
COMP2

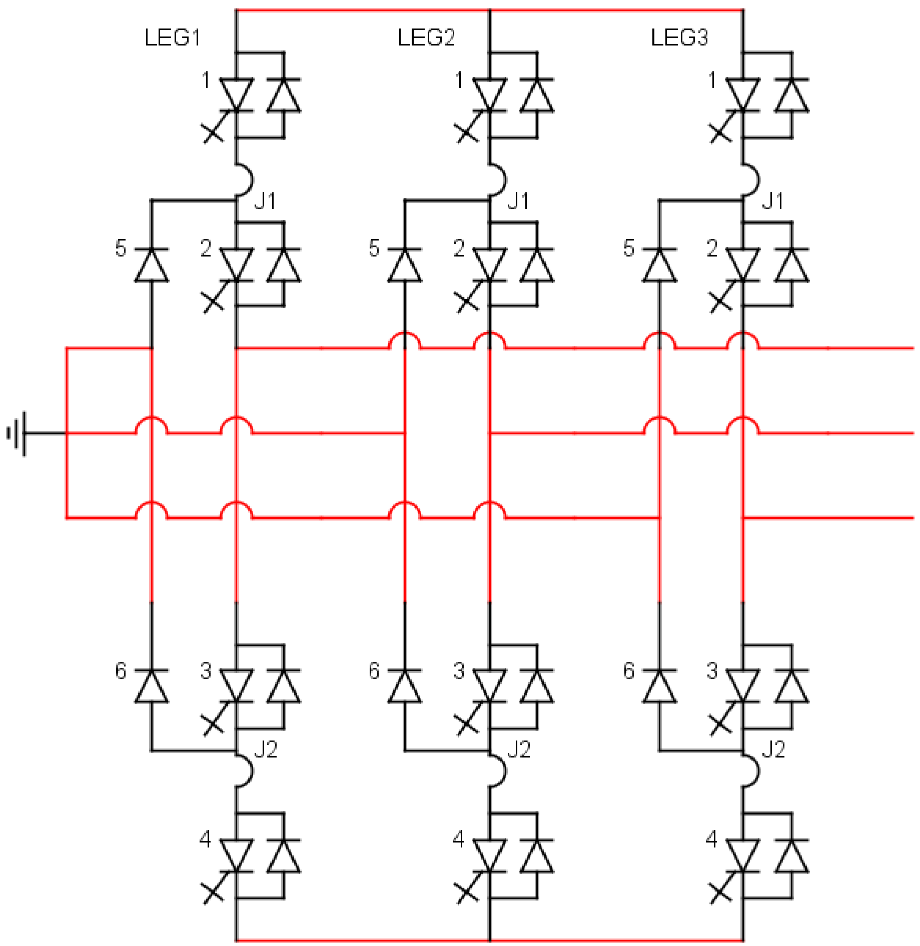
Substep or Small Timestep?

- Prior to the introduction of Substep, the Small Timestep environment was used for the simulation of power electronics and VSCs
- What are some of the differences between substep and small time step?



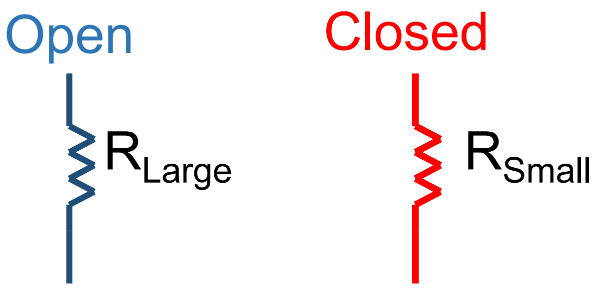
Small Δt Review – Challenges

- Simulation of high switching frequencies requires a low time step (~1-3 usec)
- Switches found within the VSC converter may require frequent re-factorization of system conductance matrix
- Real time simulation requirement makes these two challenges even more burdensome.
  - For example, if the time step is 2us, we must be able to re-decompose the conductance matrix in exactly 2us every time step.



Small Δt Review – Switch Models

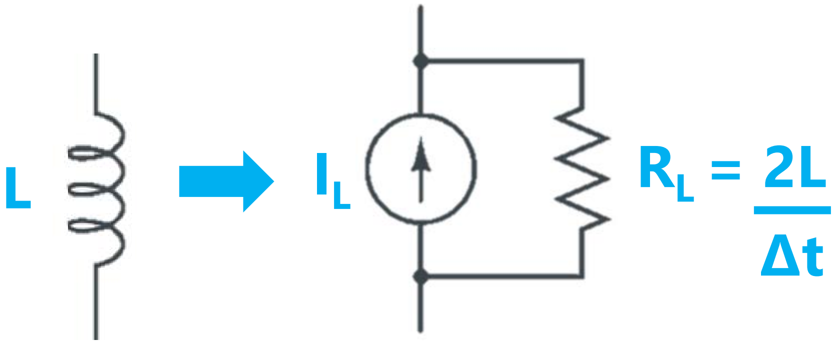
1. Resistive switching representation



The [G] matrix changes

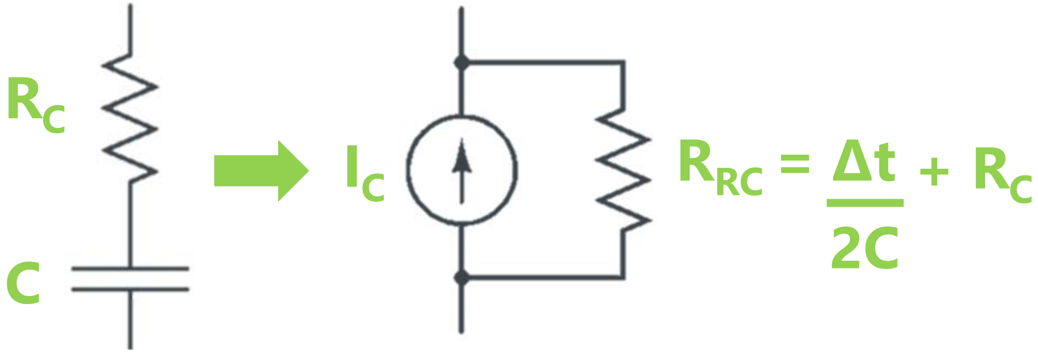
2. L/C Associated Discrete Circuit (L/C-ADC)

On-State

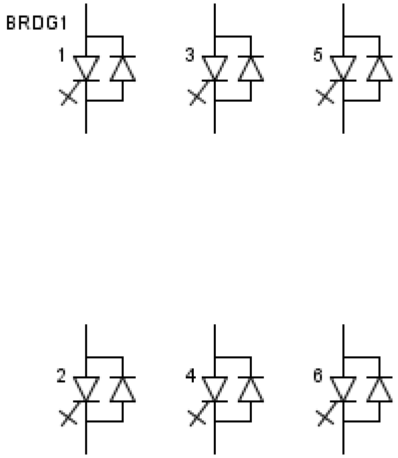


FORCE $R_L = R_{RC}$

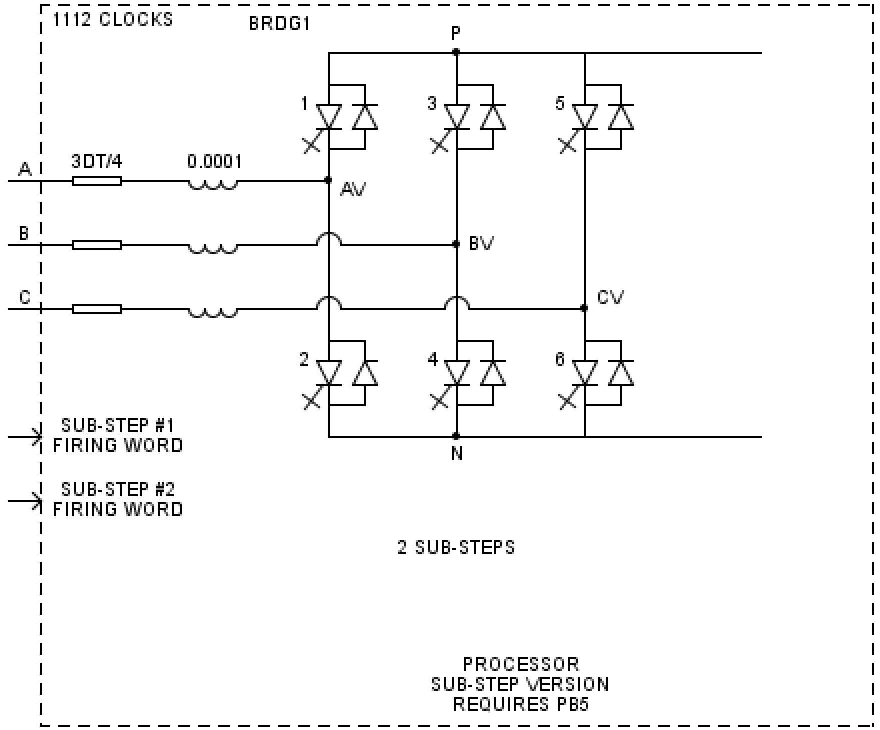
Off-State



Small Δt Review – Switch Models



L/C-ADC Switching Model
(No Interface)

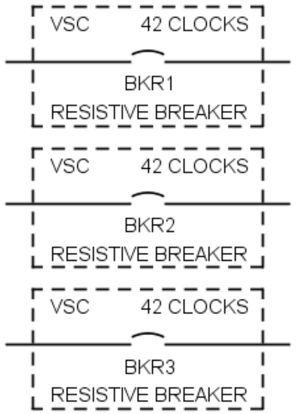


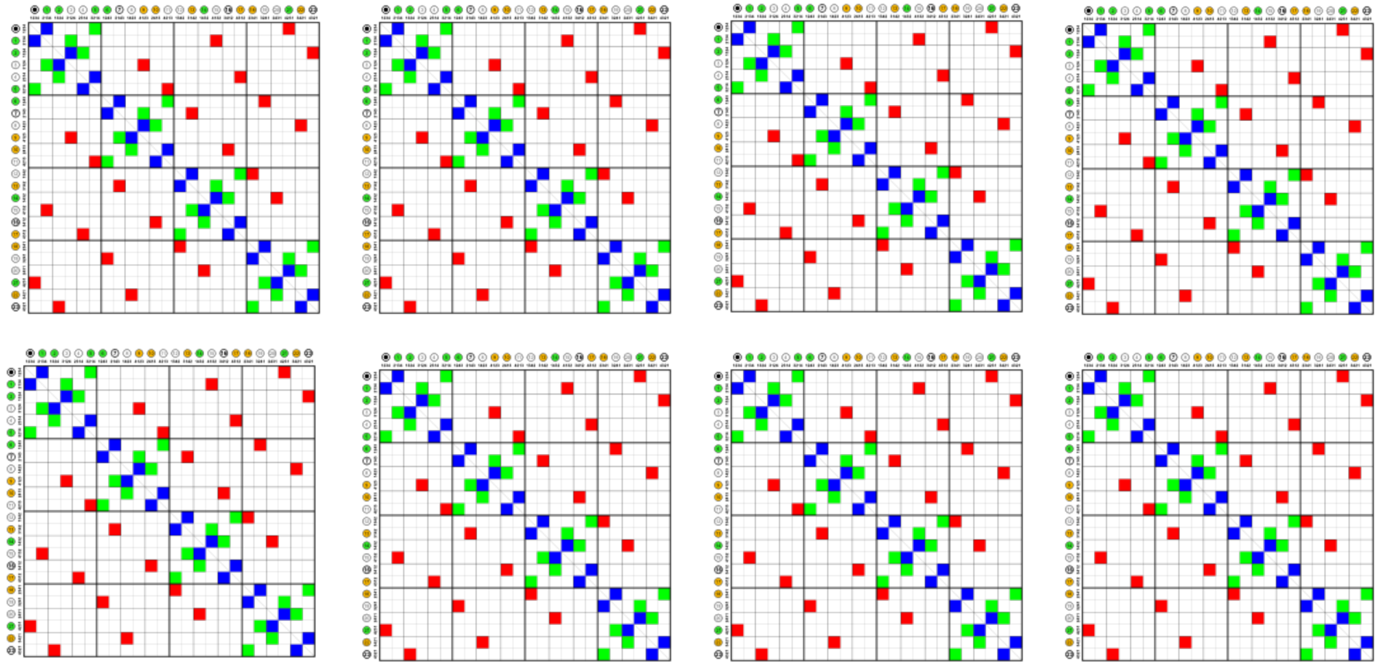
Resistive Switching Model
(Transmission Line Interface)

Small Δt Review – Network Solution

- In small timestep pre-calculated matrices are stored in the simulator
- In every small timestep pre-calculated matrix is multiplied by the injection vector to calculate node voltages
- To model resistive switches, all permutations must be stored. (2^n for n switches)
- All matrices must be stored in the processor cache
- A limited number of switches can be modeled

$$V = G^{-1} \times I$$





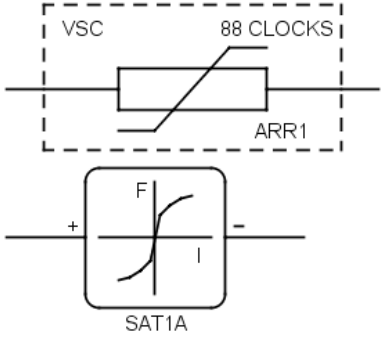
Substep – Main difference

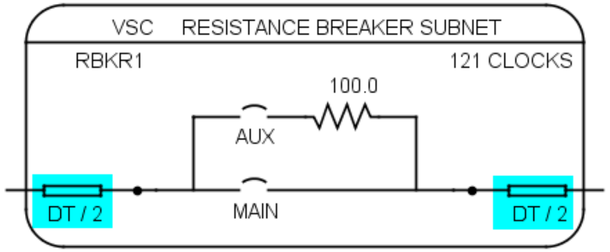
- Substep network solution solves preforms on the fly matrix decomposition every substep

→ No hard limit on resistive breakers/switches

→ More accurate models (saturation, non linear elements)

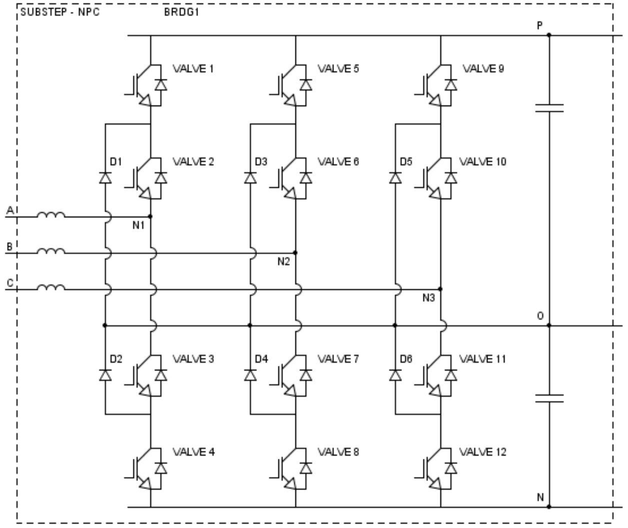
→ Resistive switching converters with no interface Bergeron lines

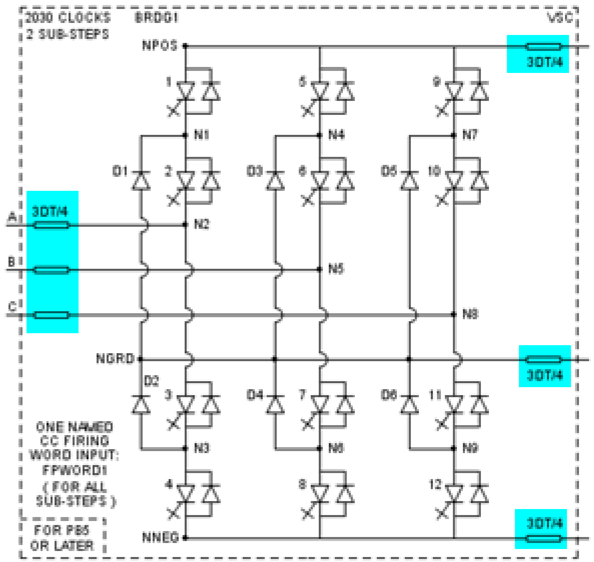




Substep

Small Time Step

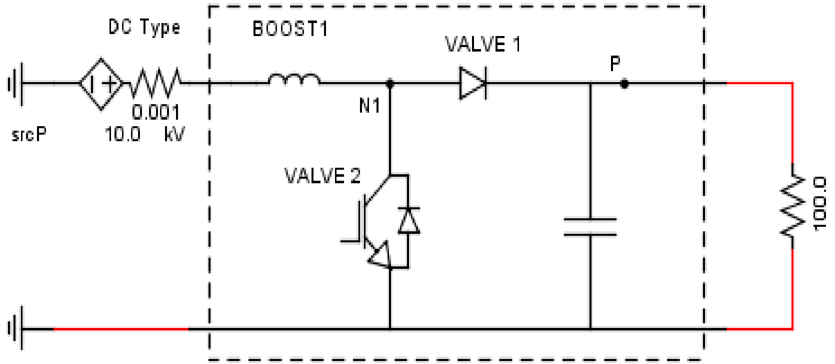




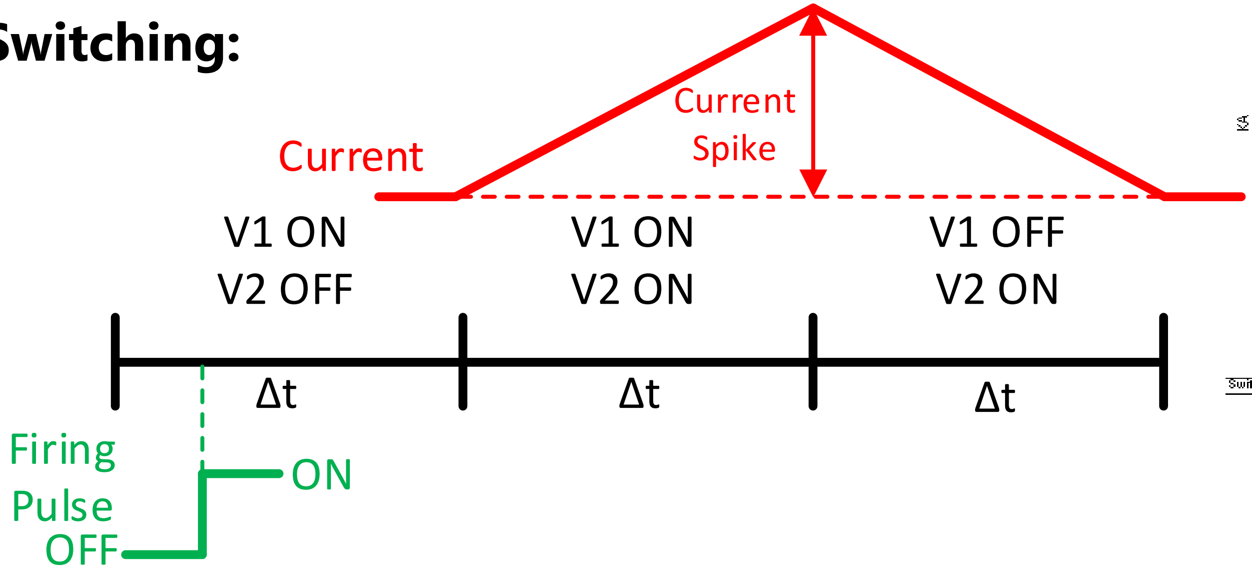
Predictive Resistive Switching

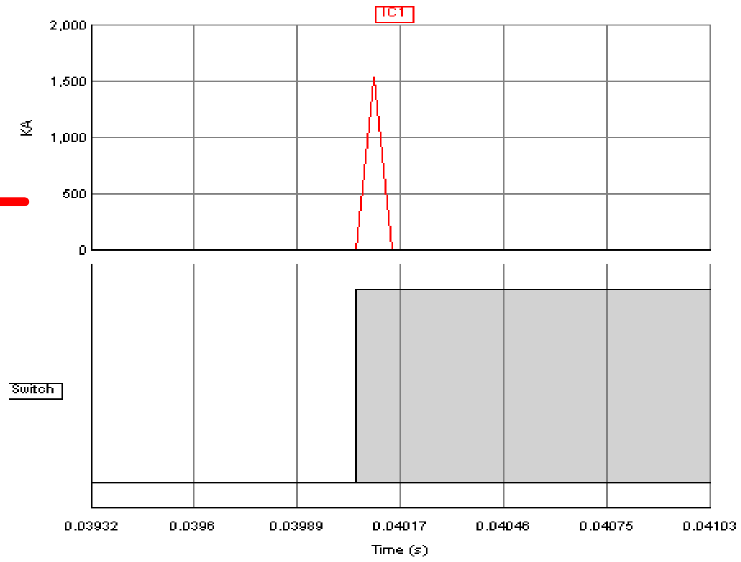
Example: Voltage Boost Converter

- Initially, IGBT Valve 2 OFF and diode Valve 1 ON
- Next, firing pulse turns IGBT Valve 2 ON
- In the next time step, both Valve 1 & 2 are ON
- This results in a large erroneous spike in the current



No Predictive Switching:

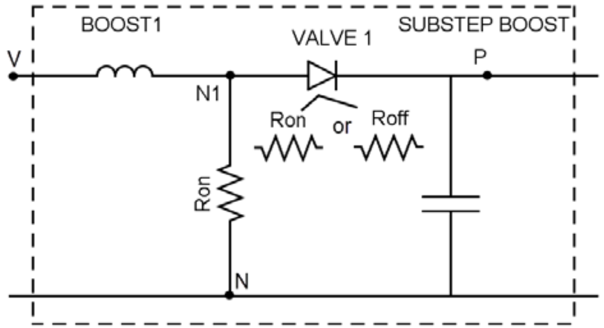




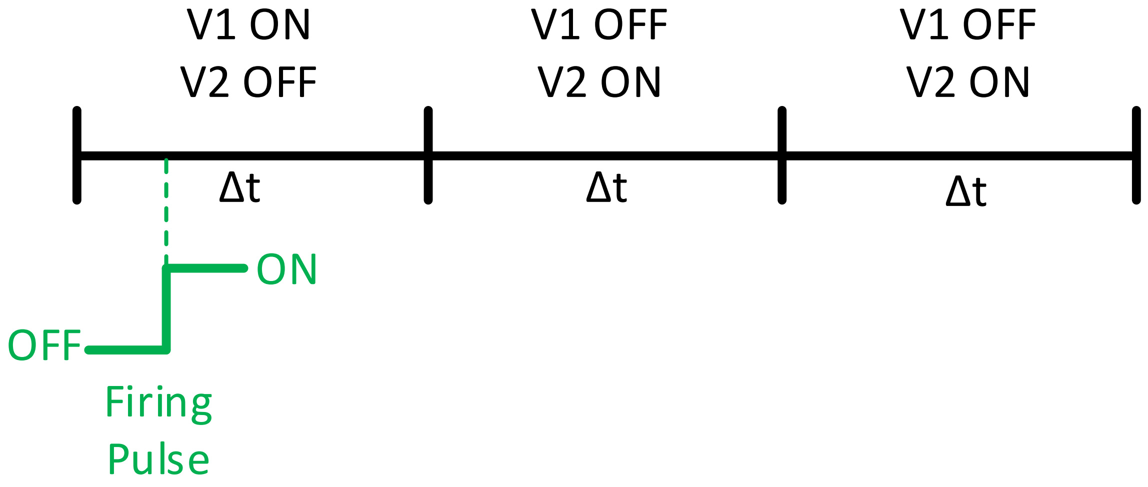
Predictive Resistive Switching

Example: Voltage Boost Converter

- With predictive resistive switching, a separate test circuit is used to search for the correct state of the diode
- This eliminates the large erroneous spike in the current



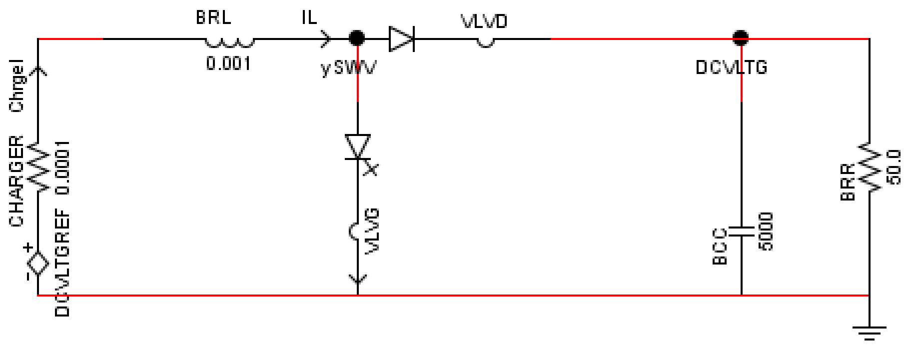
1. Assume V1 OFF (i.e. R_{off})
2. Solve for internal node voltage N1
3. Using solved N1, verify validity of assumption (V1 should be reverse biased)
4. If invalid, then V1 ON (i.e. R_{on})

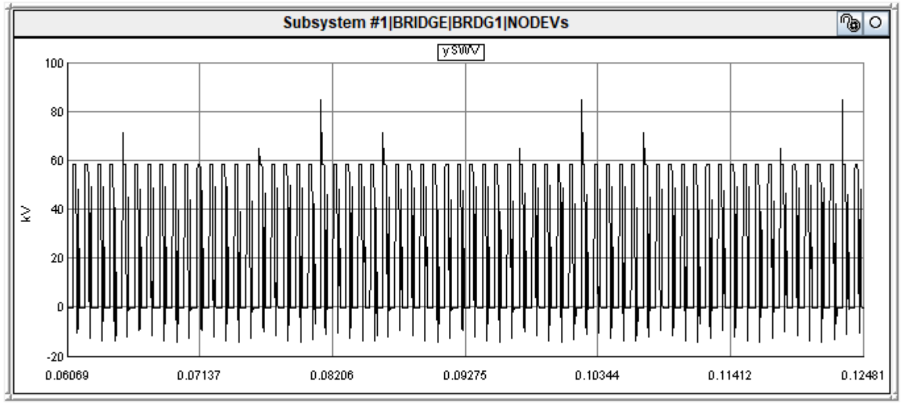


Predictive Resistive Switching

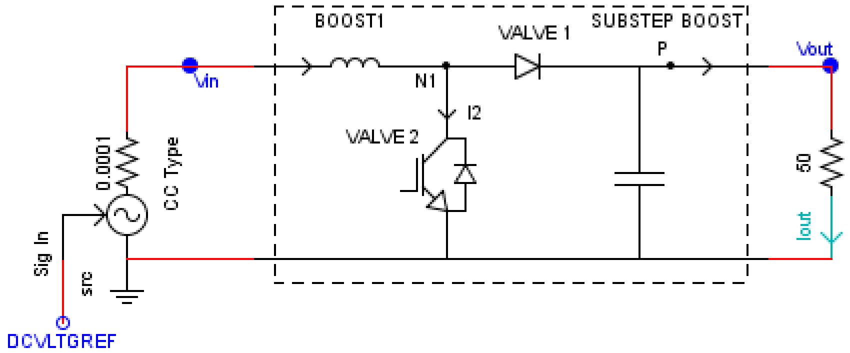
Example: Voltage Boost Converter

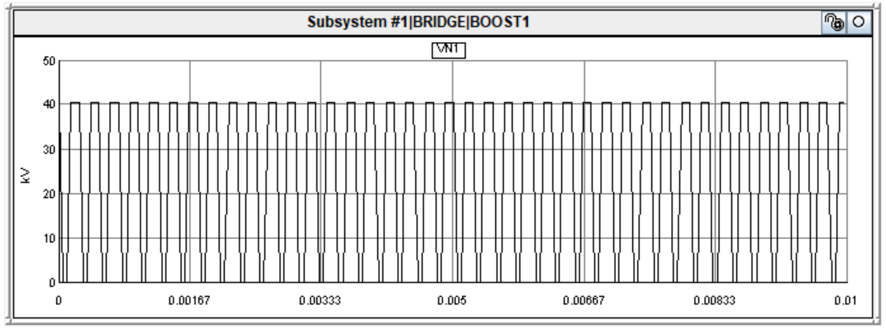
Small time step:
(No Predictive
Switching)





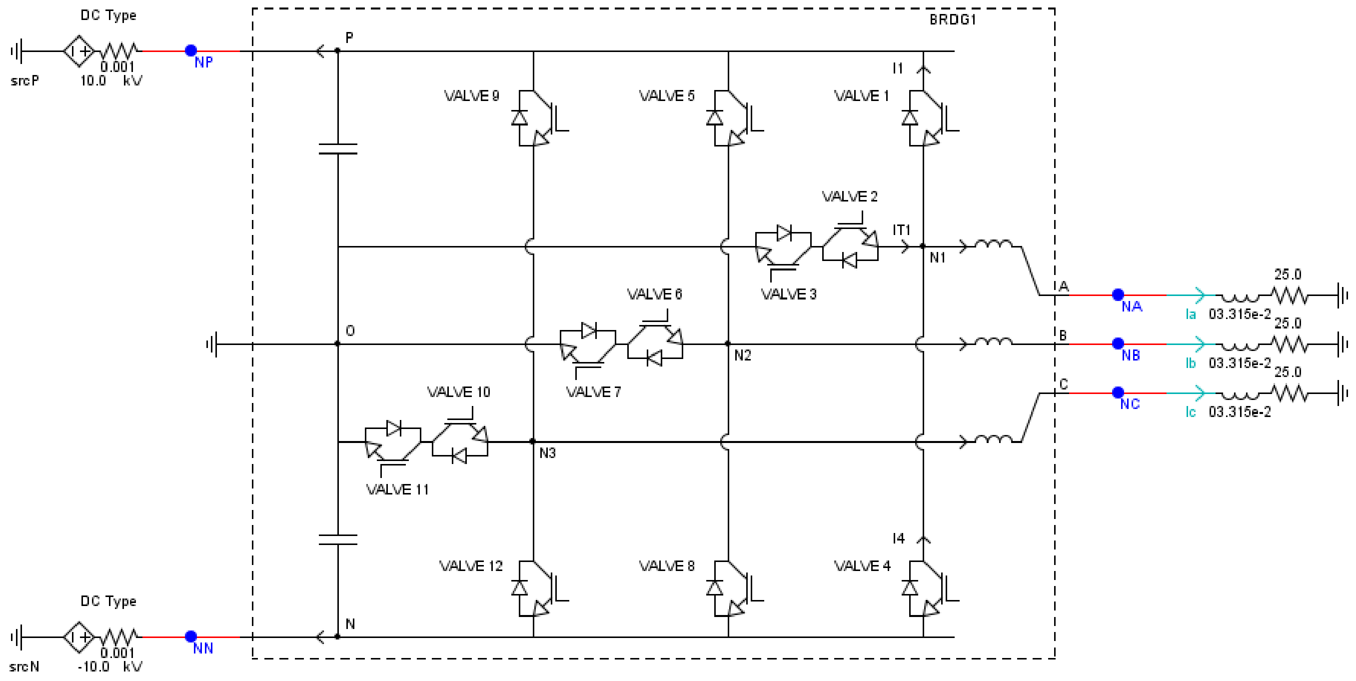
Substep:
(Using Predictive
Switching)





Predictive Resistive Switching

Example: 3 phase 3-level T-type switches resistance VSC bridge

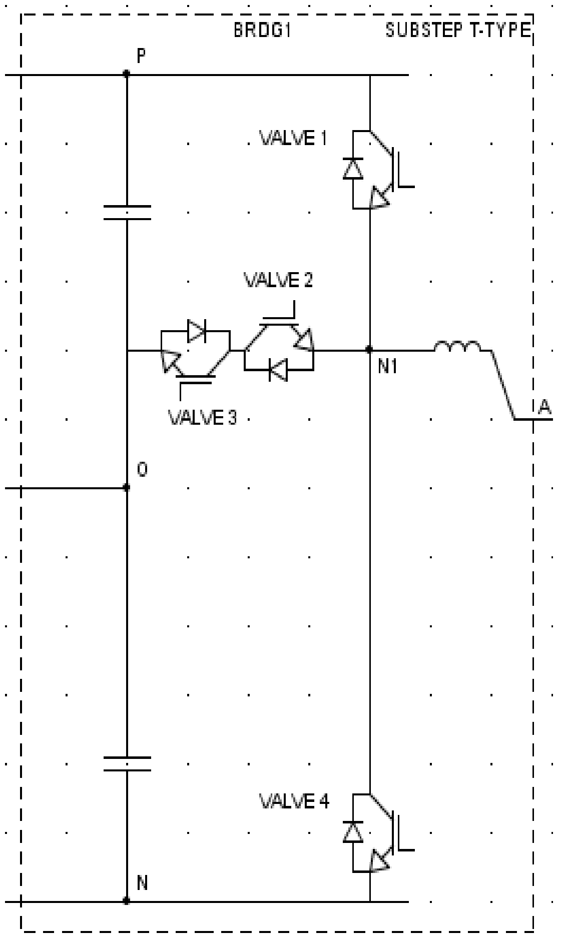


- 8 Nodes and 9 switches
- The power system components are running at 1.666 uSec time step
- Some controls (Firing pulse generators) are also running at 1.666 uSec
- High level controls are running at 25 uSec.

Predictive Resistive Switching

Predictive switching for a single 3 level T-type leg

- 2 switches connected is series with neutral path can be combined to one switch for EMT model (3 switches total)
- Test circuit is used to search for a valid combination based on the latest firing pulses, history currents, and peripheral nodes voltages
- Once found, the valid switching combination is then applied to the actual T-type bridge in the next time step



T-type resistive switching model

Predictive Resistive Switching

Predictive switching for a single 3 level T-type leg

Each switch behaves as either an **ON branch, OFF branch** or **Diode branch**

Valve 1

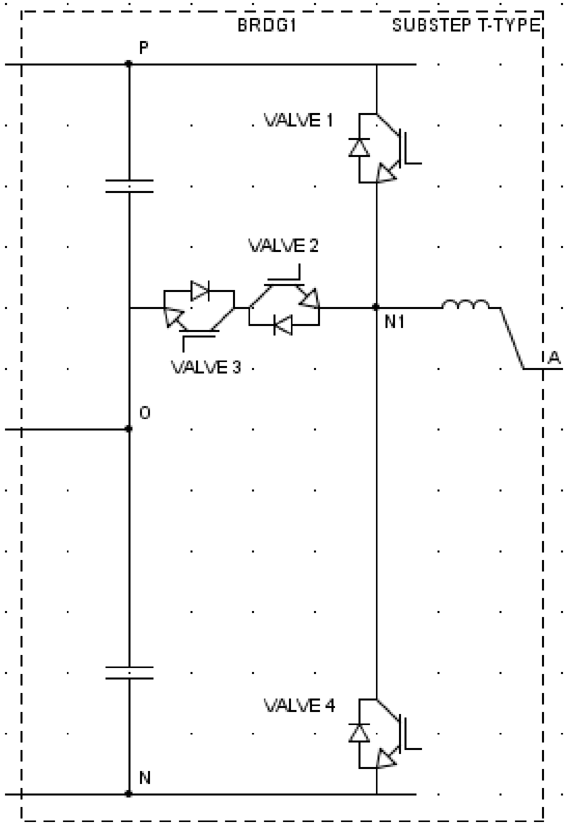
- **ON branch** when fired
- **Upward directed diode** when NOT fired

Valve 4

- **ON branch** when fired
- **Upward directed diode** when NOT fired

Valve 2 and 3 are combined as one single switch

- **ON branch** (V2 and V3 is fired)
- **OFF branch** (V2 and V3 NOT fired)
- **Diode directed toward node N1** (V2 is fired and V3 is NOT fired
- **Diode directed toward node 0** (V2 is NOT fired and V3 is fired)



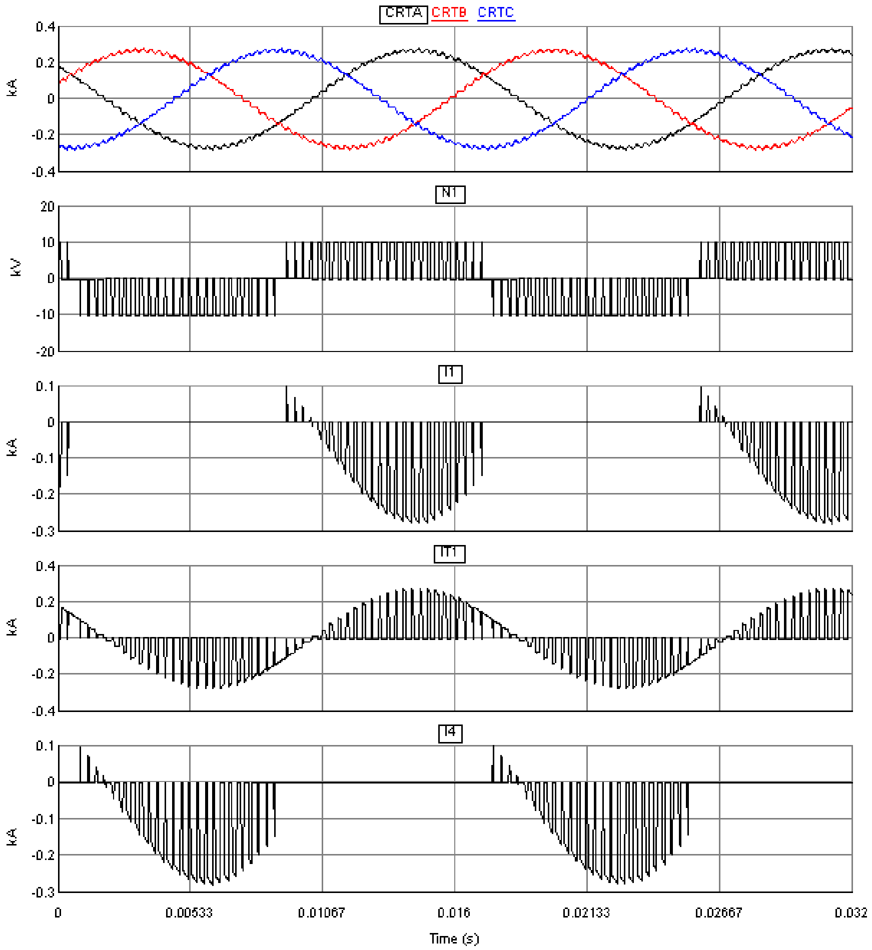
User Definable Losses

Example: 3 phase 3-level T-type switches resistance VSC bridge

Switching Frequency (Hz)	Losses (%)
3060	0.259
9900	0.333

Plots

1. AC side load currents
2. Voltage of internal phase A node N1
3. Upward current through Valve 1
4. Current through Valve 2 and Valve 3 directed to the load
5. Upward current through valve 4.



3060 Hz switching frequency

- Losses likely lower then in real physical t-type converter
- Losses can be increased by modifying the ON and OFF resistances – **User Definable Losses**

Conclusions

- Latest generation of NovaCor hardware allows for more computations in even smaller time steps
- Substep network solution preforms on the fly matrix decomposition, which allows for:
  - More resistive breakers
  - More accurate models (saturation, non linear elements)
  - Converters with resistive switching without interfacing transmission lines
  - Improved converter performance with predictive switching algorithm
  - Converter with user definable losses

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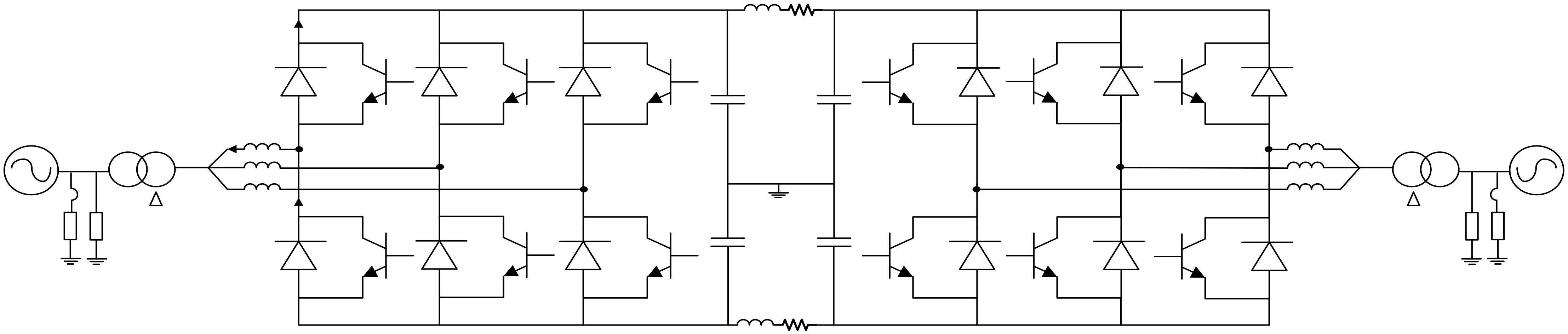
Questions?

Other Examples

Simulation Results

Case 2: Back to Back 3 phase 2 level VSC



- 28 nodes system
- 18 conductance values (12 IGBTs and 6 breakers)
- 22 nodes are connected to a switch resistive branch
- The entire circuit runs on a single core
- The entire circuit runs at **2.0** usec times
- High level controls are at 35 usec

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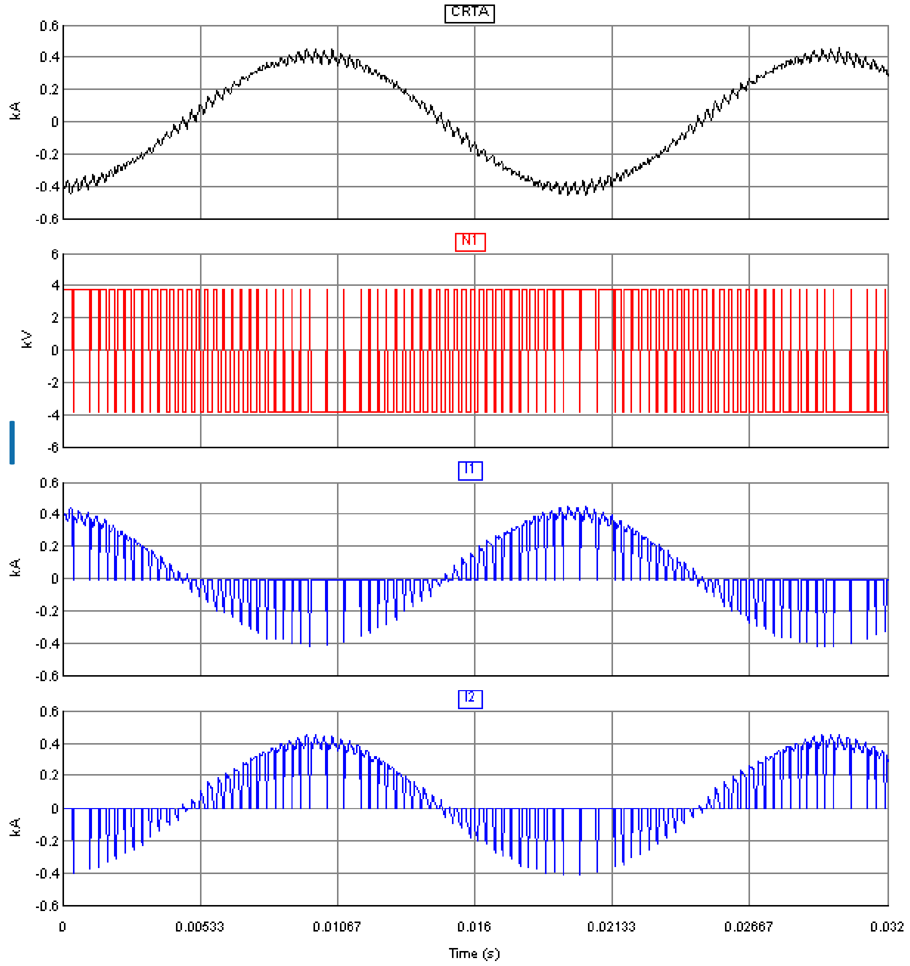
Simulation Results

Switching Frequency (Hz)	Losses (%)
3000	0.5
5000	0.51
10000	1.0

Losses can be increased by modifying the ON and OFF resistances – **User configurable losses**

Plots (left end of back to back)

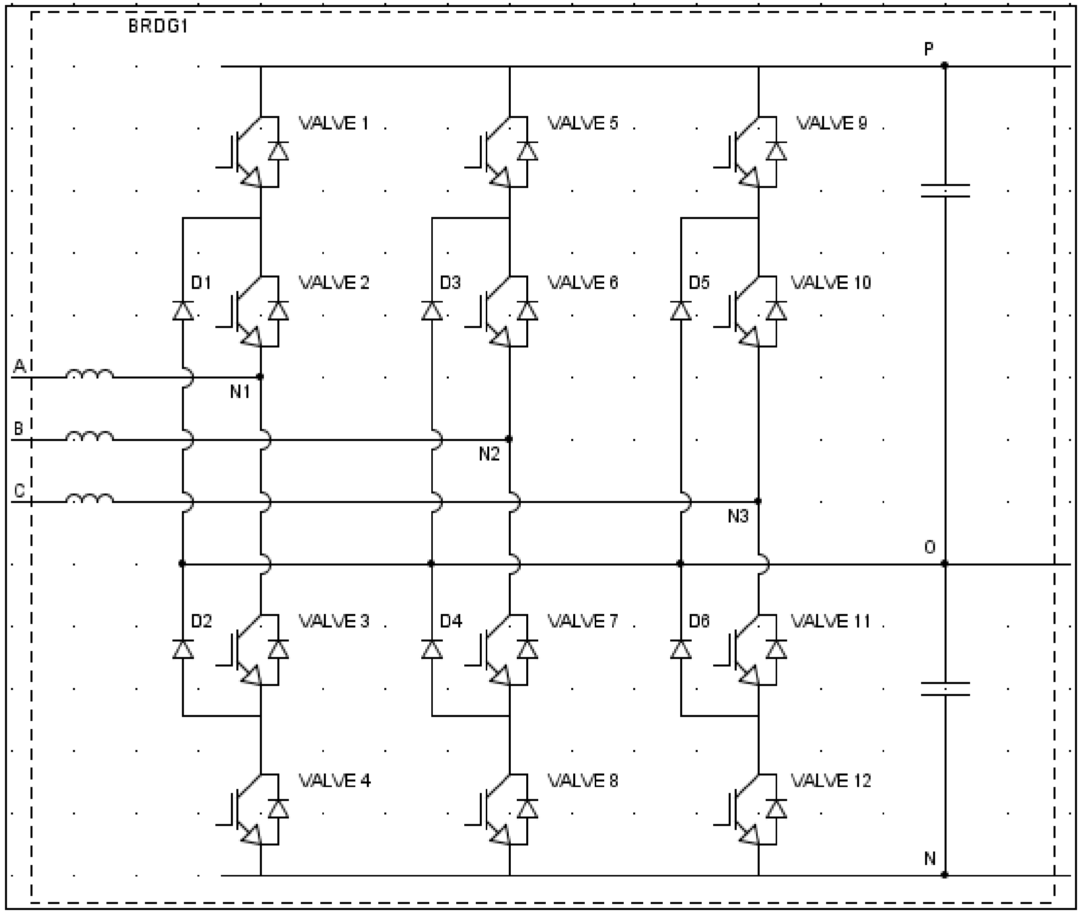
1. AC side phase A load current
2. Voltage of internal phase A node N1
3. Upper phase A valve current
4. Lower phase A valve current



3000 Hz switching frequency

3 level NPC bridge

- Each leg will have 6 switch conductances
- Corresponds to 64 different switching combinations
- 18 switched conductance values for a 3 phase bridge will be sent to the network solver
- It will be computational heavy!
- RTDS develops a NPC bridge model by conditioning a T-type bridge model
- T-Type model needs only 3 switches per leg
- Firing pulses from 3 level NPC bridge can be mapped to a T-type leg
- For monitoring, currents can be properly converted to produce correct results for a NPC bridge
- Execution time of the 3 level NPC bridge will be reduced to a time similar of a T-type leg.



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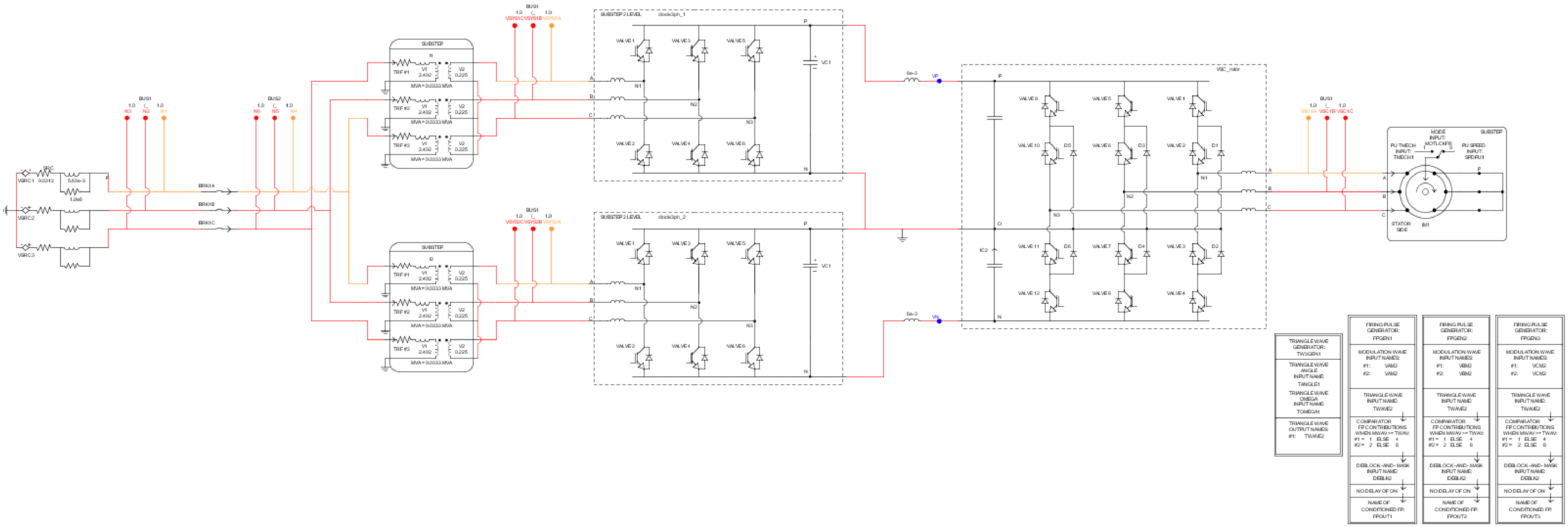
Simulation Results

Case 3: Induction Motor Drive



Simulation Results

- 26 Node system
- 24 switching devices
- 22 nodes connected to switching branch
- Two 2-level 3 phase converter bridge
- One 3-level 3 phase NPC bridge
- Induction machine model
- The system can run at substep of **2 usec**