nayak
engineer power

A NEW COMPENSATION-BASED SWITCHING MODEL FOR FASTER EMT SIMULATION OF POWER ELECTRONIC NETWORKS

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OUTLINE

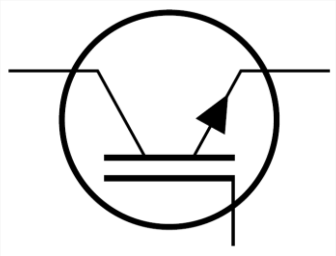
1. Brief review of emt solution method to provide a context
2. Popular switching models in emt simulators including RTDS
3. The new compensation-based switch model
4. Simulation results, comments, and conclusion

ABOUT NAYAK

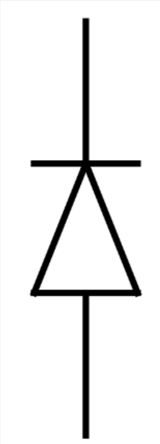
- Specialist in power systems simulation tools and services
- Independent representatives for:
  - **RTDS®** real time digital simulator from RTDS Technologies
  - **PSCAD™** emt simulator from Manitoba Hydro International
  - **DSATools™** from PowerTech Labs
  - **Power Amplifiers** from Spitzenberger and Spies
- Sales, support, and training
- Study services:
  - PSCAD model development
  - Renewable energy integration studies
  - HIL testing using RTDS
  - DER model development using PSSE and TSAT

POWER ELECTRONIC SWITCH MODEL

1. A switch is a fundamental component of any power electronics converter circuit like a Voltage Source Converter, Line Commutated Converter, dc-dc converter, etc.
2. A switch can be a controlled or an uncontrolled switch, or both.



IGBT/GTO
controlled ON/OFF



Diode
uncontrolled ON/OFF

Thyristor
controlled ON uncontrolled OFF

NETWORK SOLUTION IN EMT SIMULATION

EMT *network solution* solves

- $[V_n] = [Y_{nxn}]^{-1} \cdot [I_n]$ matrix equation every time step (Δt)
  - Y: network admittance matrix of a network of n nodes (buses)
  - V: node/bus voltage vector at time t,
  - I: current injections at time t and t-Δt
  - Δt: simulation timestep.
- The switch is represented as a controllable 2-state resistance in the admittance matrix Y.
- There are two popular approaches for modelling power electronic switch in EMT.
  - RSM: Resistive Switch Model
  - LCSM: LC Switch Model

RESISTIVE SWITCH MODEL

Two levels

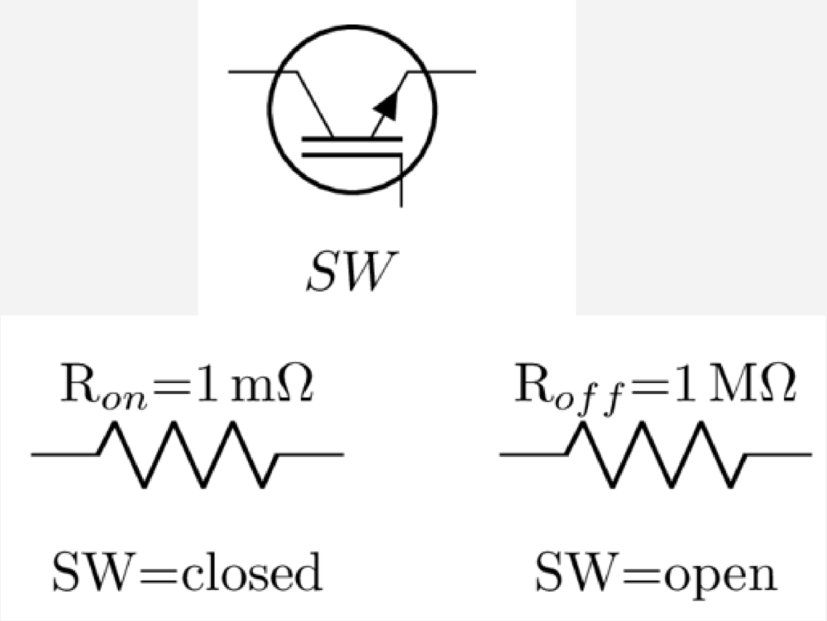
- Closed (On) switch => very low resistance branch (approx. short circuit)
- Open (Off) switch => very high resistance branch (approx. open circuit)

Advantages:

- Although approximate, it is the most accurate model
- Does not suffer from convergence problems

Disadvantages:

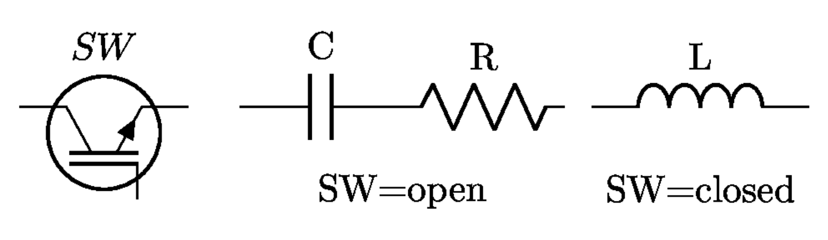
- Matrix inversion is computationally intensive
- Accomplishing in real-time is even more challenging
- Need to account for the worst-case scenario in real-time simulation leads to inefficient use of resources

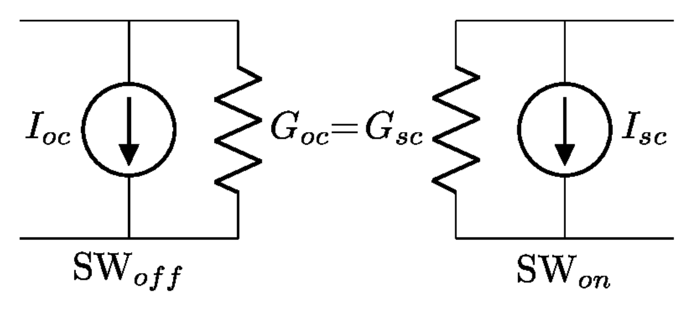


LC-SWITCH MODEL

Principle:

- The LC-switch model represents a switch as a discrete time admittance in parallel with a current source by associating the on-state of the switch to an inductor branch and off-state to a resistor-capacitor branch.
- The value of R, L, and C are selected and tuned such that the on-state admittance Gsc and off-state admittance Goc of the switch are equal
- State change is accomplished by toggling the branch association. The admittance matrix Y remains unchanged.





Advantages:

- The system admittance matrix Y is time-invariant and can be set before start of the simulation
- No matrix inversion during switching event is involved
- Predictable network solution time and large computational savings

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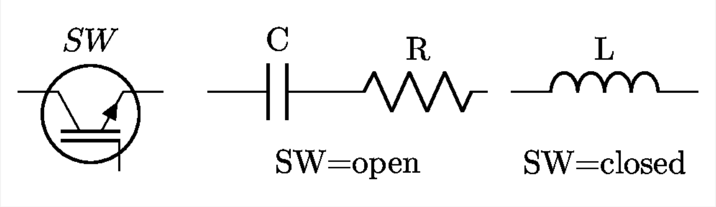
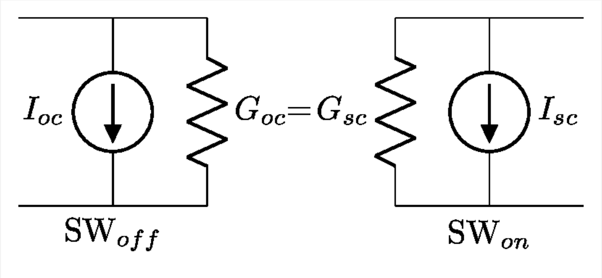


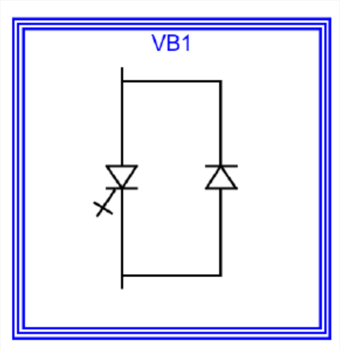


Disadvantages:

- LCSM is still an approximation of the open and closed states of a switch
- Necessitates using small timestep of the order of a few micro-seconds.
- Generates artificial storage and loss of energy between the inductor and the capacitor.
- Energy exchange is spurious and can result in inaccurate simulation, if not handled carefully.
- Extra computational burden at lower timesteps. Plotted waveforms unnecessarily appear distorted and spiky.

RTDS SWITCH MODELS

- RTDS simulator has both RSM and LCSM switches
- LCSM is used in Small-dt simulation environment
- RSM is used in Sub-step simulation environment



WOULDN'T IT BE NICE IF WE CAN HAVE …

A switch that combines the advantages of both RSM and LCSM

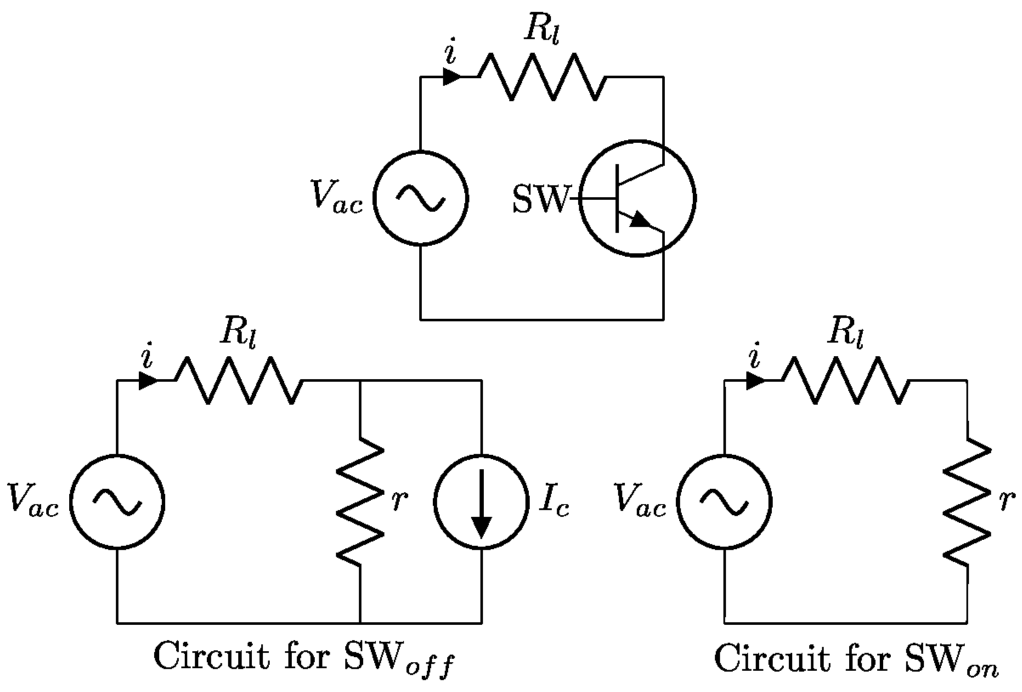
A NEW COMPENSATION-BASED SWITCH

- The proposed switch combines the benefits of both RSM and LCSM, which implies it also eliminates the disadvantages of both
- Constant network admittance matrix like LCSM,
  - i.e., no time-step dependency
- Robust and accurate over a very wide frequency range like RSM,
  - i.e., no spurious pulses, oscillations, and fictitious loss issues like LCSM
  - does not require parameter tuning
- Simple to implement like RSM and easy to program in the existing EMT formulation.

Compensation-based switching model has it all

A NEW COMPENSATION-BASED SWITCH

How does the compensation-based model work?

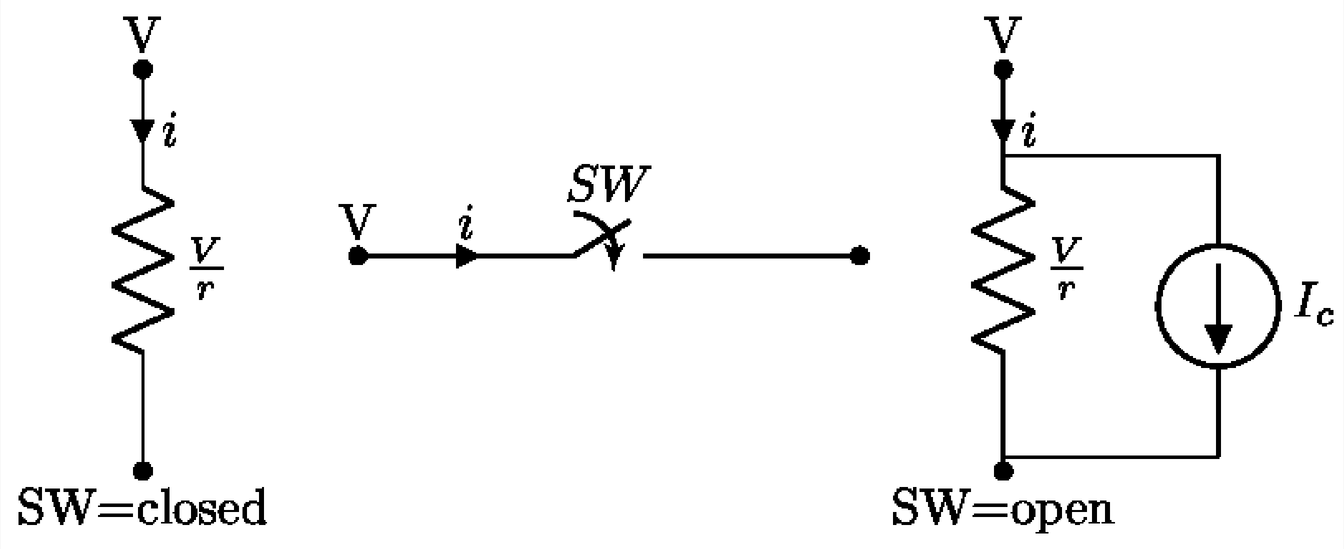


Open State

Closed State

A NEW COMPENSATION-BASED SWITCH

- Turned-on (Closed) state = small resistance, say r.
- Turned-off (Open) state = same r, as in the turn-on state, but with a parallel current injection source to represent turn-off state



This keeps the admittance matrix Y constant.

A NEW COMPENSATION-BASED SWITCH

If the network solution equation at time t=0 is $Y \cdot \hat{V} = I$

- A solution structure after a switching event can be represented as $(Y + \Delta Y) \cdot \hat{V} = I$

  - where ΔY is the change in admittance due to switching

- It can be re-arranged as

$$(Y + \Delta Y) \cdot \hat{V} = I$$

$$Y \cdot \hat{V} = I + \Delta \hat{I}_{pre}$$

and, $\Delta \hat{I}_{pre} = -(M \cdot c \cdot M^{t} \cdot Y^{-1}) \cdot I$

where, M and c are auxiliary matrices generated or used during the mathematical manipulation.

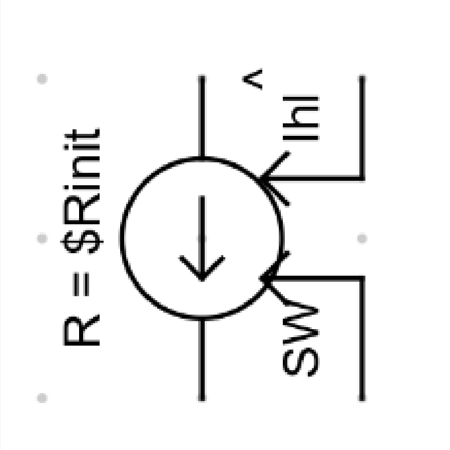
This method is popularly known as “inverse matrix modification lemma”.

A NEW COMPENSATION-BASED SWITCH

- It should be noted that equation $Y \cdot \hat{V} = I + \Delta\hat{I}_{pre}$ means we are using only a single matrix Y throughout simulation and that $\Delta\hat{I}_{pre}$ is the current injection computed post switching and pre (before) network solution.
- This methods of adding a suitable switching-based current injection to the original current injection is known as pre-compensation.
- Post compensation is also possible, where the equation gets slightly modified to $\hat{V} = V + \Delta\hat{V}_{post}$, that is adding suitable switching-based voltage vector to the solution obtained from network solution.
- Pre-compensation is suitable for controlled devices like IGBTs or GTO or Thyristors.
- Post-compensation is suitable for uncontrolled devices like diodes.

COMPENSATION-BASED SWITCH MODEL FOR RTDS SIMULATOR

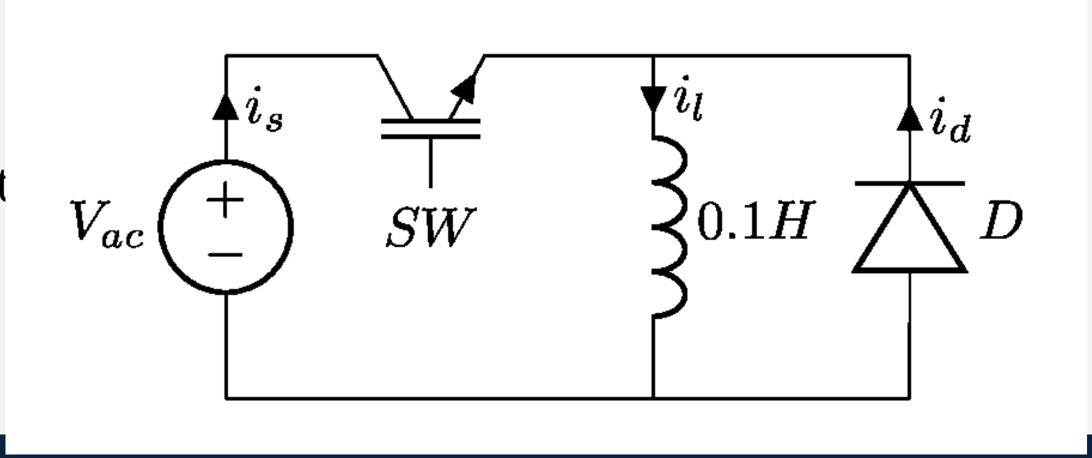
- CBuilder in RSCAD gives users a convenient facility to design custom components
- CBuilder script allows adding current injections before the network solution
- Hence, it is easy to create a *pre-compensation switch* as a custom component
- The component shown was written using CBuilder
    - SW is the firing pulse input
    - Ihl is the history current injection
    - current injection is calculated as in the component script
    - SW is the firing pulse input
    - Ihl is the history current injection



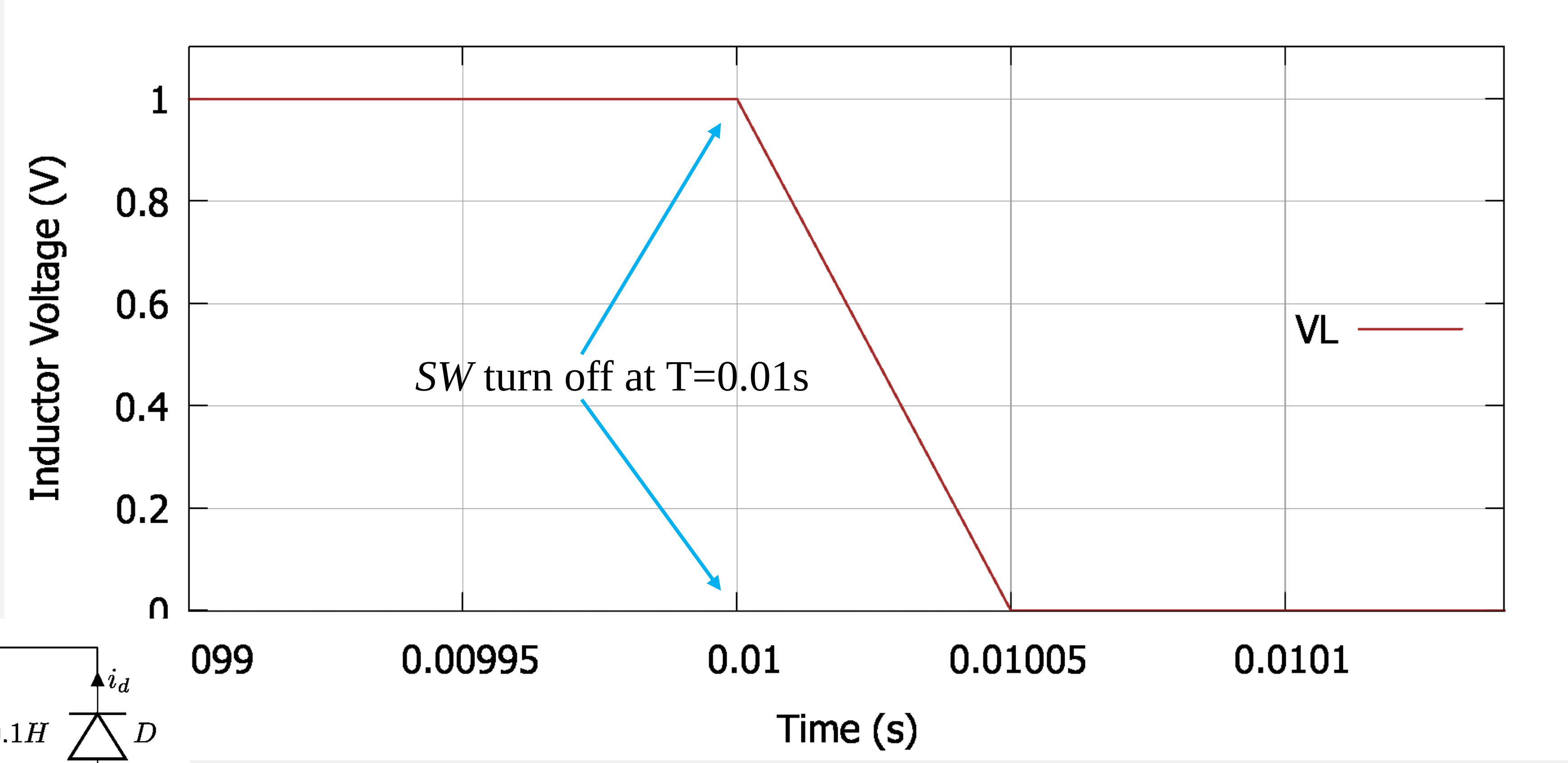
COMPENSATION MODEL IN A SIMPLE CIRCUIT

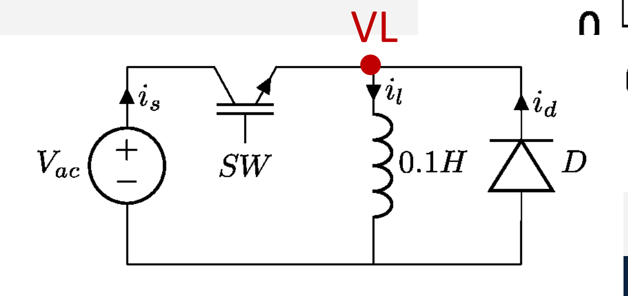
- The circuit shown below explains the pre and post compensation models
- The (controlled) switch (SW) uses pre-compensation to inject the compensated currents before network solution – The equation to be solved is then $Y \cdot \hat{V} = I + \Delta\hat{I}_{pre}$.
- The Diode (uncontrolled) switch state is determined post network solution and modified solution vector $\hat{V}$ is calculated using $\hat{V} = V + \Delta\hat{V}_{post}$
- $\Delta\hat{I}_{pre}$ and $\Delta\hat{V}_{post}$ are pre & post compensation vectors

ONLY PRE-COMPENSATION
was possible as a custom component

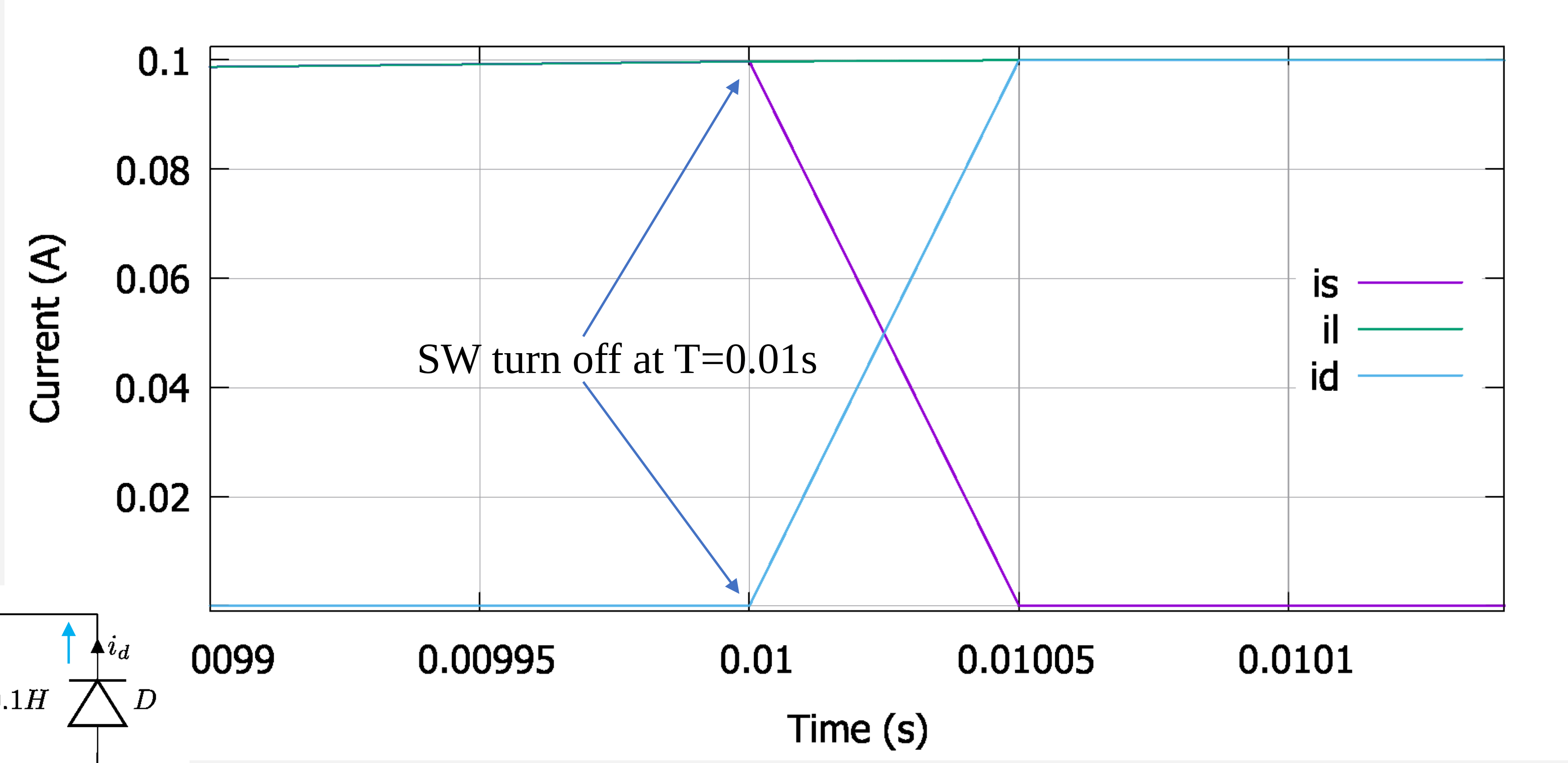


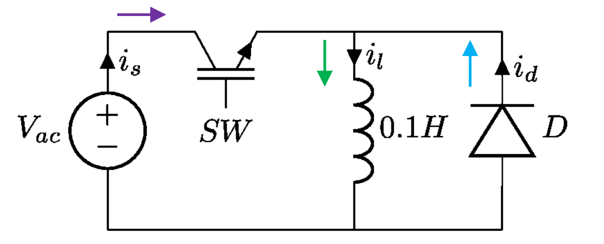
COMPENSATION MODEL IN A SIMPLE CIRCUIT





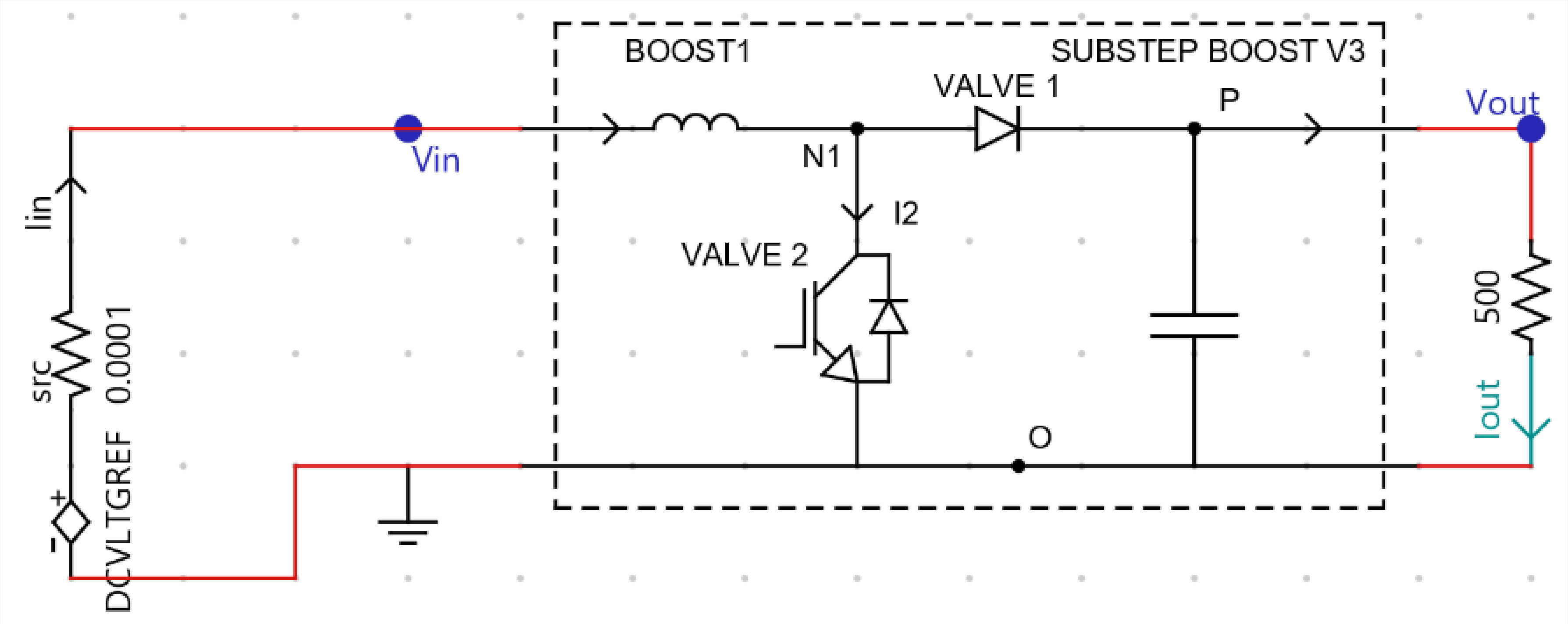
COMPENSATION MODEL IN A SIMPLE CIRCUIT





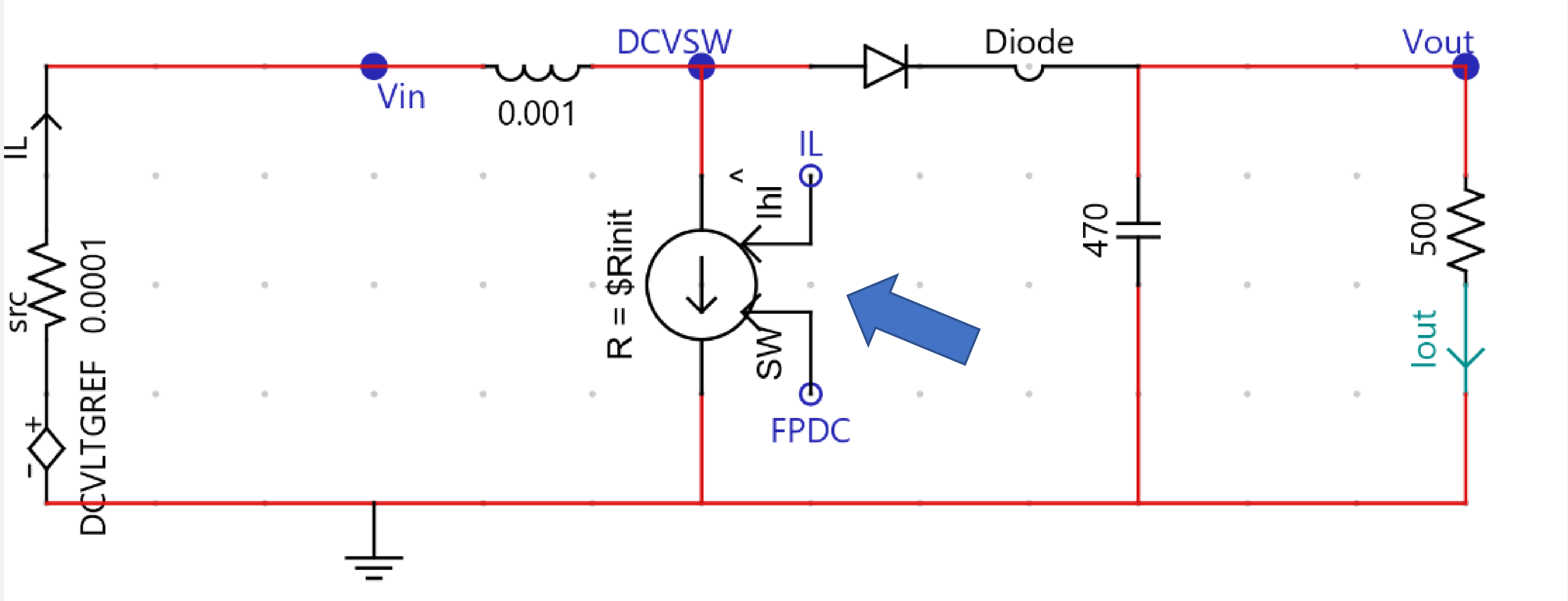
SUBSTEP BOOST CONVERTER MODEL IN RSCAD

- Boost converter case from RSCAD examples directory



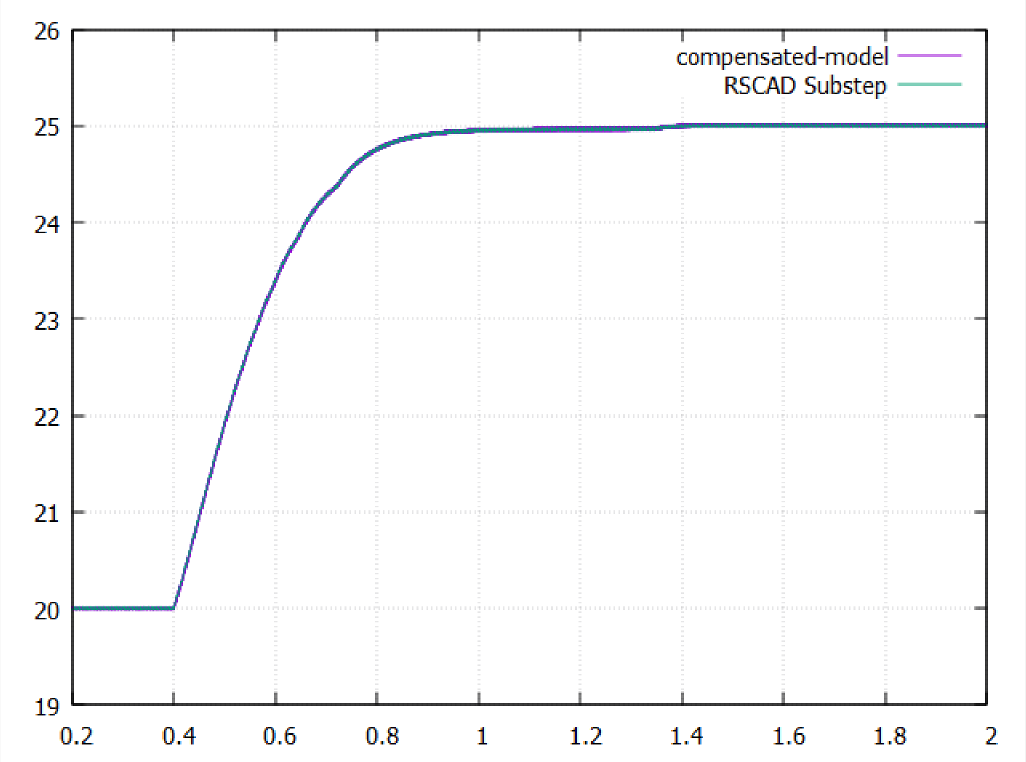
COMPENSATION-BASED BOOST CONVERTER MODEL IN RSCAD

- Boost converter example from RSCAD that uses compensation based switch model



RESULTS

- The figure shows comparison of output voltage of the boost converter using Substep model and the pre-compensated model of a switch
- Timestep used is 2us
- Both waveforms overlap



SOME COMMENTS

- If $Y \cdot V = I$ is the original solution, then
  - Y^{-1} before switching must be known – Y^{-1} is needed to compute the auxiliary matrices required by the matrix inversion lemma.
  - The current injection vector I must be known and accessible
  - The auxiliary matrices all are pre-computed and add $4n-1$ flops extra for each switching component where n is the order of matrix Y. The number of extra flops is far less than refactorization or new decomposition after switching
- This is a very early stage of experimenting with this method
- There are many aspects of practical use of this technique which are yet to be explored
- In other-words, don't ask tough questions ☺

CONCLUSIONS

- The compensation model of a switch:

1. Generates a constant system admittance matrix irrespective of switching, thus avoid refactorization or decomposition of the system matrix.
2. Gives an accurate solution with no cumulative errors, without any approximation in the math.
3. Does not generate any spurious oscillations, pules, or artificial losses.
4. Does not put limitations on the switching frequency for accurate of solution.
5. Adds a small overhead to the network solution process.
6. Can be easily adapted in the existing EMT structure of RSCAD or PSCAD.

ACKNOWLEDGEMENT

- We would like to acknowledge the help extended by RTDS Technologies to answer queries related to network solution and boost converter simulation.
- Special thanks to Heather Meiklejohn and Udeesha Samarasekera for their help while implementing the custom component in RTDS