
Application note

High-impedance snubber adjustments for ARTEMiS TSB

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Opal-RT Technologies

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Document revision history

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1. Executive summary

This document objective is to explain how to correctly adjust Opal-RT Time-Stamped-Bridges (TSB) with regards to the high impedance RC snubbers used to force null currents when all gating signals are turned off.

The document explains 2 methods to quickly set the RC snubber of TSB. The first one uses an analytic approach to find the R-C values. It has the disadvantages of requiring an estimation of circuit inductance. The second method involves some iterations and guessing but works most of the time in any given circuit.

2. Software Requirement

Table 1 List of Software required

Software Names	Versions
MATLAB	R2015a

3. TSB variants

TSB exists for many topologies: 2-level inverter, 3-level NPC inverter, MMC, etc... Their internal working principle also varies. All Opal-RT TSBs are capable of interpolating voltage outputs according to RT-Events or H FPGA-HIL sampled gate signals. Additionally, for the TSB technology of Opal-RT, there are currently 2 types of TSB approaches with regards to the modeling of non-active working mode such as high impedance or natural rectification mode:

Classic TSB: these TSBs implement high impedance and natural rectifying modes by using a current-nulling feedback control. These TSB have the inconvenience of requiring a good tuning of the PI control, equivalent in equation to a series RC snubber.

TSB with real diode (TSB-RD): These TSBs uses actual SimPowerSystems (SPS) diodes to simulate high impedance and natural rectifying modes. The major inconvenient of these models is that the number of coupled SPS switches can become quickly high enough to forbid real-time simulation. In that case, users can use SSN to solve this high switch count problem to decouple the TSB-RD into different SSN groups.

The following sections relates to **Classic TSB** that can be found in the ARTEMiS library, in ARTEMiS/Tools/Custom Model section.

It is worth to mention that the stabilisation technique of Section 4.3 also works for TSB-RD.

Note that this do not apply to the first generation of TSB of the RT-Drive library, a library currently in obsolescence mode. These old TSB did not support high impedance mode.

4. RC-snubber and PI control in TSB

TSB are essentially controlled voltage sources as are also in essence real voltages inverters. However, they can become (zero) controlled current sources in the case where all IGBT and diode are OFF. To circumvent this problem, TSB implements a zero-current close-loop control in that case. The Proportional-Integral control has an equation similar to an R-C snubbers and therefore is called 'High-Impedance RC-snubbers'.

These snubbers must be tuned to minimize the output current of the TSB in this high-impedance mode without causing instability.

The TSB documentation sometimes propose calculation methods for the R-C snubber. These method are however difficult to implement because they depend on load inductance, a quantity that is sometimes difficult to evaluate or can vary in time.

We propose here an alternative practical method to obtain the best results possible with the TSB, based on iterative simulations

4.1 Classic derivation of TSB snubber for stability

An important non-standard working mode of TSB is when one or more phases opens at the inverter or between the inverter and the motor. This integration method causes a delay to be included in the loop and causes instability when R is too high. In FPGA models, the stability issue is less of a concern because of the very small time step used.

To actually make sure the average open-phase current tends to null itself, the open-phase impedance has been modeled as a *PI* controller, whose parameters are determined by stability considerations. We suppose here that the TSB drives an inductive load that can reach a minimum value of L_{min} . The maximum Proportional gain (or $R_{snubber}$) value is then equal to the Forward Euler stability limit:

$$R_{snubber} \leq \frac{2 * L_{min}}{\Delta T}$$

where L_{min} is the minimum inductance of the load and ΔT is the simulation sample time. It is suggested that $R_{snubber}$ be set to less than half the limit above to provide some stability margin. With only $R_{snubber}$ (i.e. only P feedback), the equivalent circuit of a TSB in high impedance mode can be described by the following circuit:

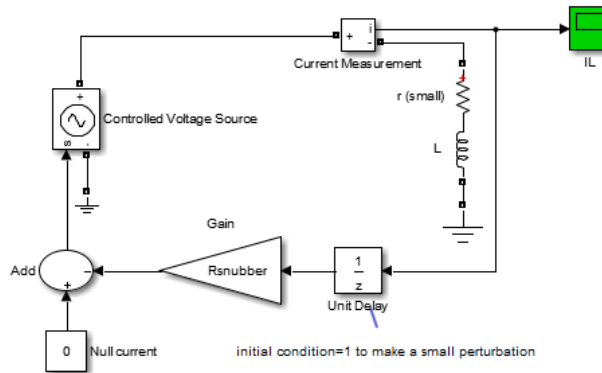


Figure 1: Equivalent circuit of TSB in high impedance mode

The Integral Gain can be viewed as capacitor in series with the resistor. One option is to set its value is set so that the resonant frequency between L_{min} and $C_{snubber}$ (which is the inverse of the PI Integral gain) 10 to 50 times lower than the sampling frequency of the simulation.

A simpler approach is to view $C_{snubber}$ has a stabiliser for the switching logic in the SSN or SPS solvers. In this case, we set $C_{snubber}$ so that the RC time constant equals some multiple of the simulation time step. This gives:

$$C_{snubber} = k * \Delta T / R_{snubber}$$

where the value k is typically set between 2 and 4. Lower k is better because it produces a higher impedance.

4.2 Analysis of TSB snubber for stability using Bode Analysis

TSB stability can be analyzed with Bode analysis. An example of Bode analysis stability is given in section IV of [1].

4.3 Practical method to find optimal RC snubber values.

The problem of analytic methods in finding RC snubber values is that they assume that the load inductance is easy to evaluate. In reality, it's rarely the case. TSB loads can be complex, composed of switches and time-variable like in machines.

Using iterative simulations, we propose a method to find the best RC snubber values. Ideally, we would like a very high value for R and a very small value of C.

Let's say you want to find the best RC snubber value in a model with a TSB. Set the model so that IGBT pulses are initially OFF, then turned ON for a small moment (a few cycles of fundamental frequency), then turned OFF for good.

- 1- Set $C_{snubber} = inf$, Set $R_{snubber} = 'very\ low'$ By very low, we mean a value that would NOT create numerical instability right from the start of the simulation. In doubt set $R_{snubber} = 1\Omega$ for example.
- 2- Run the model
 - a. If the model is stable, do $R_{snubber} = R_{snubber} * 2$ and repeat Step 2-
 - b. When the model is unstable, keep the last stable $R_{snubber}$ and continue to Step 3-
- 3- Set $C_{snubber} = k * \Delta T / R_{snubber}$ where the value k is typically set between 2 and 4.

Smaller k are better because a smaller capacitor will produce a higher total snubber impedance. Snubber impedance is equal to $R_{snubber} + \frac{1}{j\omega C_{snubber}}$ for ω frequency at the load.

Reversed method: Some people may prefer to start with a very high value of $R_{snubber}$ and an unstable simulation then to decrease $R_{snubber}$ in step 2- until the model becomes stable. This is fine.

4.3.1 Where and how to look for instability in a model

Instability can occur when an IGBT bridge shutdown its pulses. There are then 2 possibilities:

- 1- The load current goes to zero (ex: passive loads or induction motors).
- 2- The load equivalent back-EMF put the TSB in a natural rectification mode (ex: PMSM at high speed or DC-link charging in no-pulse mode).

Case with somehow passive TSB loads: look for the load currents in pulse shutdown mode. This current should go close to 0. Some residual current can remain because of the current going through the snubbers.

Case with back-EMF and rectification: One should look for the inverter AC voltage to be stable. This is the voltage at the connection between the TSB and the motor or AC grid (ex: Active Front end rectifier working in no-pulse mode).

4.4 References

[1] Christian Dufour, "Highly stable rotating machine models using the state-space-nodal real-time solver", COMPENG-2018 conference, Florence, Oct. 10-12, 2018, available in the Scientific Paper section of ARTEMiS.