

Bladed model simplification for real-time execution with Bladed Hardware Test Module

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1 INTRODUCTION

In hardware in the loop (HIL) mode, full fidelity Bladed models usually run slower than real-time (e.g. a simulation of 10mins of turbine operation takes more than 10mins to compute). In order to use a Bladed model in a HIL configuration executing in real-time it is therefore often necessary to simplify the model. This simplification unavoidably reduces the accuracy of simulation, but for many applications sufficient accuracy can be retained.

For the purpose of testing a wind turbine controller, if the primary concern is only to check correct logical operation of the control software – i.e. it goes through the expected sequence of steps, executes in real-time, and remains stable, but turbine loading is not being studied, it is reasonable to aggressively simplify the model.

If the model is to be used in a HIL component test rig application, where turbine loads are important, the simplification must be done more carefully, and in some cases it may not be possible to achieve desired accuracy in real-time.

Note: If parts of the Bladed model are encrypted then you will probably not be able to simplify them. The only option then is to ask the supplier of the encrypted part to simplify that part for you.

This tech note was written for Bladed 4.11 and BHTM 2.3.0.14. The principles are the same for other versions, but some names and dialogs may be different.

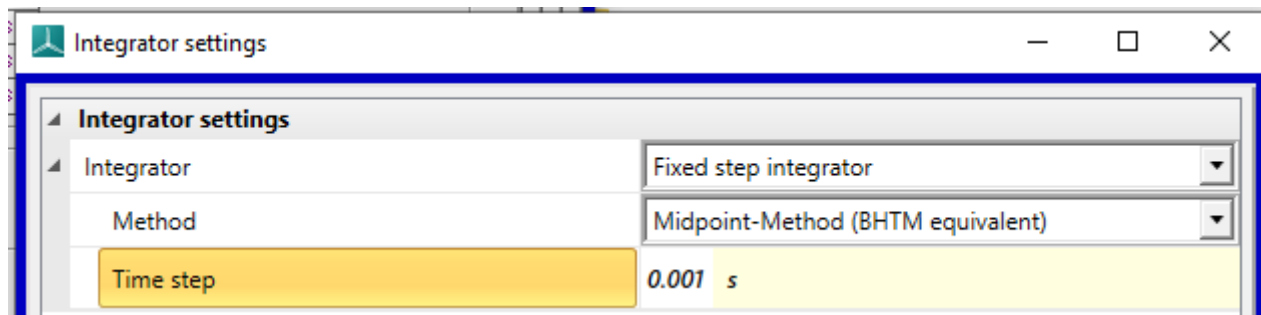
2 PROCESS TO SIMPLIFY BLADED MODEL

It is suggested to do most simplification initially using a plain Bladed Power Production simulation. Once this is running reliably with adequate speed then it can be incorporated it into a BHTM simulation.

2.1 Simplify in Bladed Power Production run

To allow Bladed Power Production simulation to execute with similar timing to a BHTM simulation the integrator for Bladed must be set to Fixed Step and Midpoint-Method. This is specified in the Integrator settings dialog.

Start with small integrator step time, say 1ms.



Configure Power Production calculation for a short simulation, say 20s.

Run the simulation, and while it is running compare by eye the elapsed time in the DOS window to real-world time.

```

c:\dnv gl\bladed 4.11\DTBLADED.exe
Init vspr
*** External Module Note: Init vspr
Time=      17.018000s:   17.23 RPM;   -0.19 deg pitch;  2014.777 kW

```

Alternatively, add the following text to Project Info window for dtbladed and timing information will appear in the .\$.RT file.

```

MSTART EXTRA
REAL_TIME_OUT Y
MEND

```

The goal of the simplification is to get simulation time to pass faster than real world time. At first it will likely be much slower.

To speed up the simulation, try increasing the integrator Time Step, or make simplifications as detailed in section 3. The fewer high frequency modes are present in the model, the larger the time step can be without causing instability. Simplification is an iterative process.

If the step time is made too large, then the simulation will become unstable. The symptoms of instability may not be obvious. Bladed is unlikely to directly say that the simulation is unstable – more likely errors will start to arise, e.g. 'blade hit the ground', or 'wind file too small'.

Once a Power Production simulation will clearly run faster than real-time, extend to use BHTM.

2.2 Configure Bladed model for use with BHTM

The following configuration of the Bladed model is needed to work with BHTM.

It is recommended to begin BHTM simulations with the Bladed model in Idling state and allow the turbine controller to perform startup to power production. In Control -> Supervisory Control -> Idling, tick "Enable external controller" and set initial pitch angle to feather angle.

If an External Controllers (discon.dll) is defined, ensure it points to a valid dll (this isn't actually used when running BHTM, but Bladed can't start the simulation if it can't find the external controller dll).

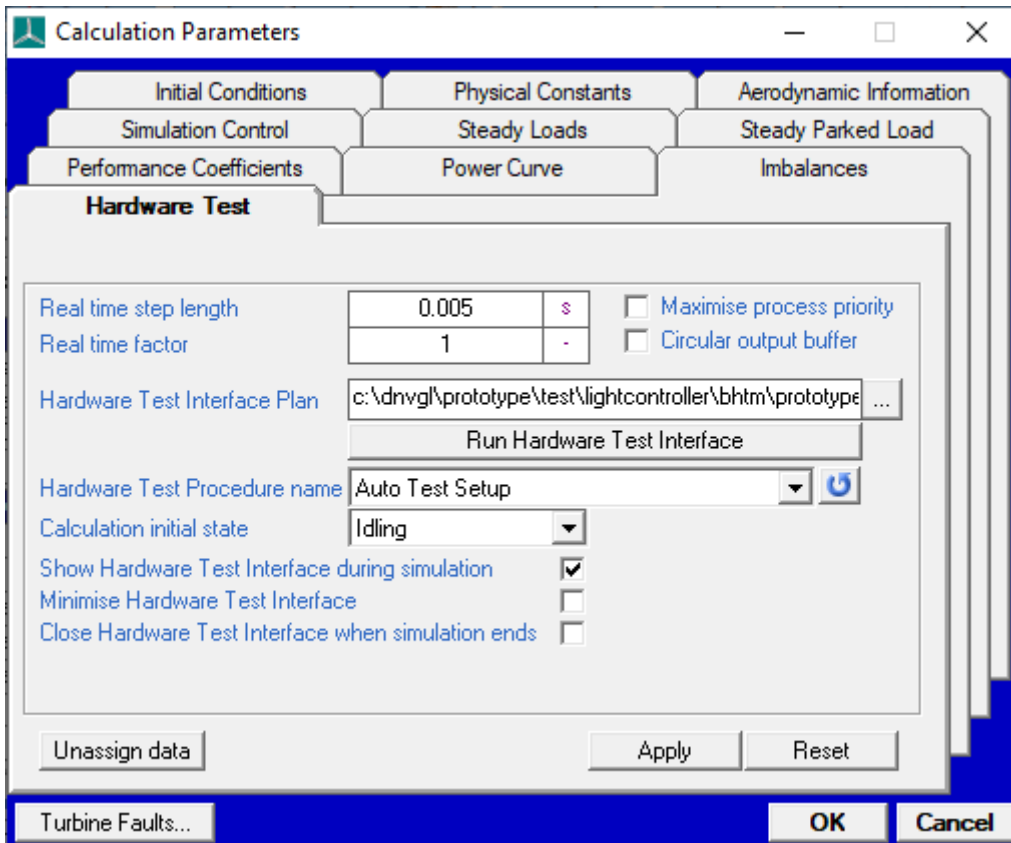
In Calculation Parameters -> Hardware Test:

- Set the *Real time step length* to the step time found during the previous stage using Bladed, or a shorter time.

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- Select the BHTM .plan file you wish to run and select a test procedure
- Set the simulation initial state to Idling

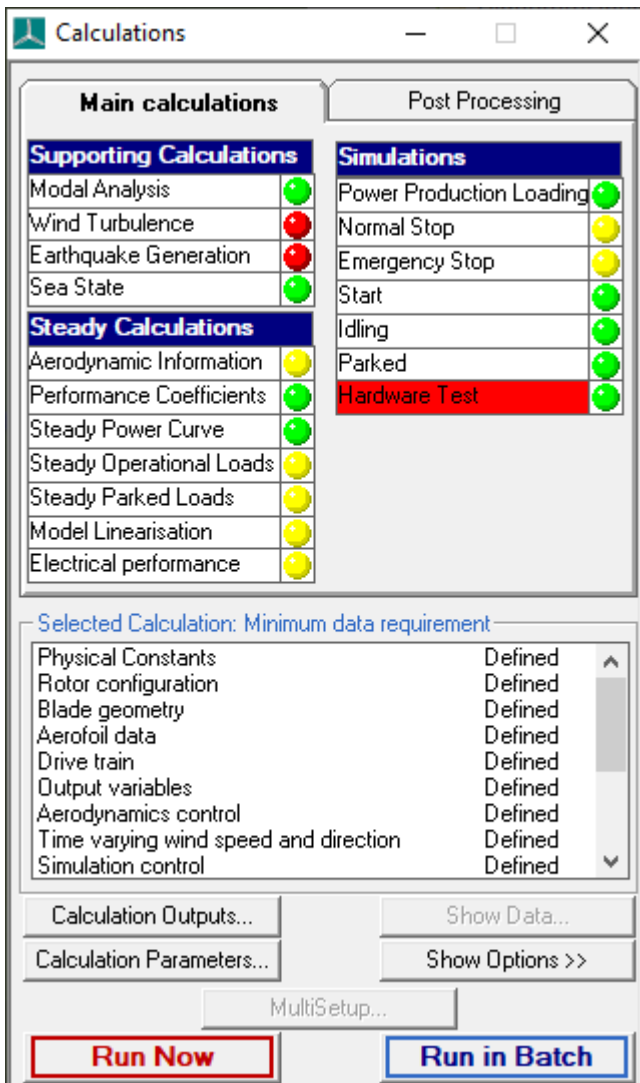
For example:



In Simulation Control, set 'Length of output buffer' to a value much larger than the expected duration of the BHTM simulation (this sets the time between Bladed writes of simulation data to file. These writes upset real-time execution, so we wish to postpone them to after the simulation completes)

In the Project Information screen, check if there are any special options defined in the 'Special data' window for dtbladed.exe (e.g. MSTART EXTRA ... groups). If there are, then the same text must be copied into the 'Special data' window for Bladedsim.dll too.

It is recommended, at least initially, to launch BHTM simulations from the Bladed UI, by selecting Hardware Test calculation and clicking Run Now, as shown below.



It is also possible to start BHTM simulations directly from the BHTM UI (though this is sometimes less robust – in case of problems try launching from Bladed). To allow starting from BHTM, ensure that the Bladed project file is saved with Hardware Test calculation type selected (as in picture above).

2.3 Check operation with BHTM

Finally we can check the execution timing in BHTM.

Create a BHTM test procedure that begins with a long wait, e.g. 1minute, and save the test plan.

Select this procedure in the Bladed Hardware Test dialog, and click Run Now. The BHTM UI should open and the test begin running. Once it completes, Export simulation results (right click in the data table in BHTM) to whatever format you prefer to look at results in.

The BHTM results includes timing data for each BHTM Device. Two values are of primary interest:

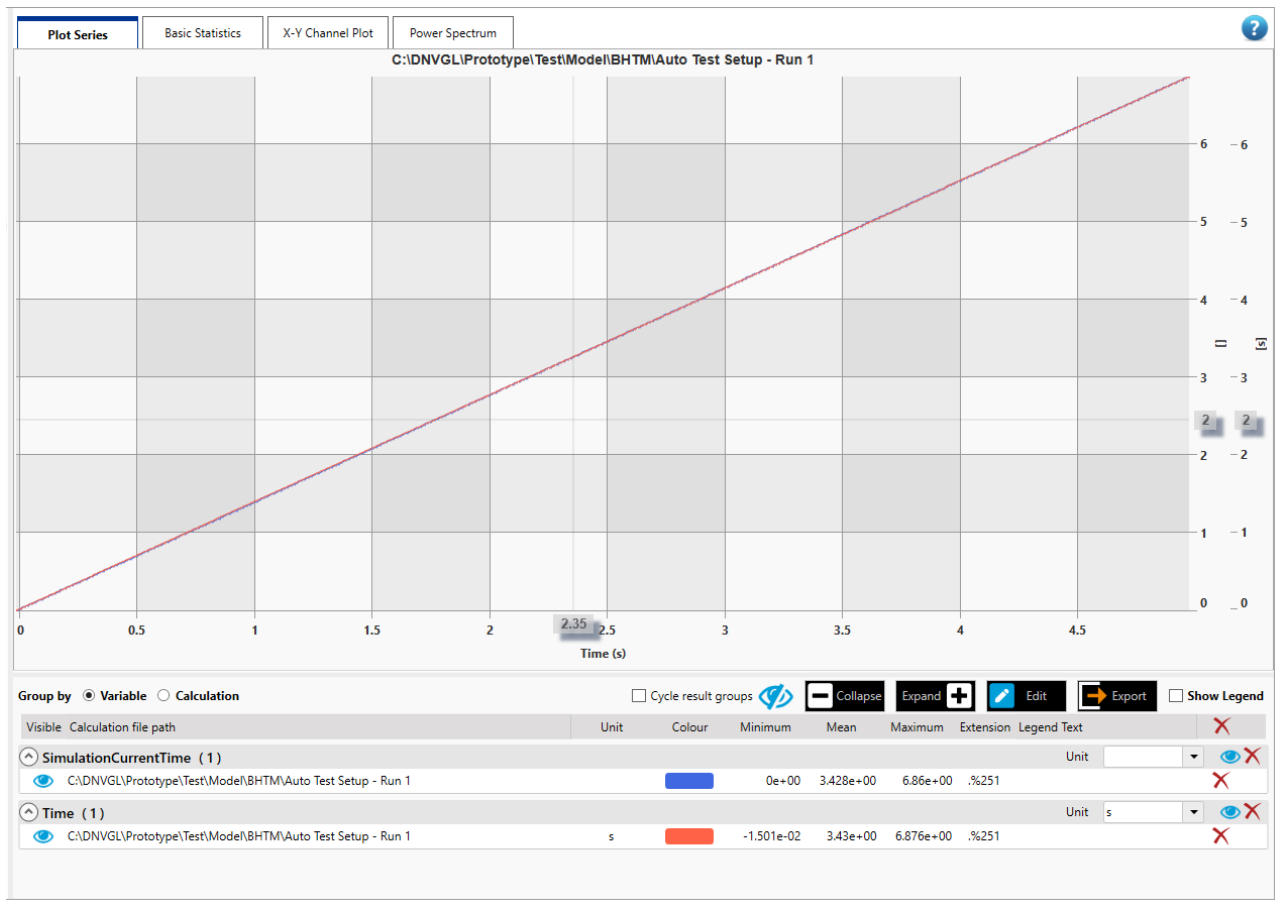
- UpdatePeriod – the time from the start of one simulation step to the start of the next step

- ExecutionDuration – the time from the start of one simulation step to then end of that step.

In the following plot you can see timing for a Bladed model with good timing performance. It is configured for 5ms step time, ExecutionDuration is almost always well below 5ms, and UpdatePeriod is steady at 5ms. The few exceptions are very brief spikes, possibly due to Windows non-determinism, and would not interfere with most BHTM simulations.



Another useful check is to compare 'SimulationCurrentTime' (elapsed time inside the Bladed simulation) to 'Time' (elapsed real-world time). If real-time execution is being achieved, then these 2 lines will lie on top of each other. If they diverge the Bladed model is too slow.



If the BHTM simulation starts, but then either BHTM crashes or the test fails unexpectedly, a likely cause is that the Bladed model is unstable. If decreasing the step time for BHTM results in simulations that run, but are too slow, then continue the process described earlier to further simplify the model.

2.4 Win32 Dll devices in BHTM

If any BHTM device is a win32 dll in debug build, for example turbine controller source code built to a dll rather than a PLC executable, and you are having timing problems, try using a release build instead of debug build. In some cases it has been observed that using a debug build of a dll causes Bladed to run much slower. This may manifest in BHTM results as both the Bladed model & the controller being much slower.

3 BLADED MODEL SIMPLIFICATION OPTIONS

This section details changes that can be made to the Bladed model to increase execution speed. None of these are essential, and which ones are appropriate will depend on the specific application.

3.1 Wind

Using turbulent wind requires significant computational power. Steady wind is often sufficient, or even desirable for clarity, for controller testing.

Note: BHTM can vary wind speed & direction during a simulation by specifying an offset from the mean wind speed and direction in the Bladed wind definition. This requires the BHTM test plan to know what the mean wind speed & direction in Bladed are, so ensure that what you specify in Bladed for wind speed & direction matches what the BHTM test plan assumes if it is doing any offsetting.

3.2 Power Train

Set the drive train to rigid with no dynamics.

Remove slipping clutch or brake.

Disable any high frequency electrical dynamics defined in the Bladed model. A simple 1st order passive response should suffice.

3.3 Blades

Reduce the number of blade stations (under the Blade Geometry tab in the Blades module). Remove stations where there is minimal variation in blade geometry, e.g. away from the root, as this will have the least effect on model dynamics. Approx 10 stations is reasonable.

3.4 Tower

Reduce the number of tower stations under tower structure in the tower module. As for blades, it is best to remove stations where there is minimal variation in geometry from adjacent stations, and approx. 10 tower stations is reasonable.

3.5 Flexibility

If the blade is multi-part, convert it to single part. Choose the "axial loads only" geometric stiffness setting for the blade. Choose the "internal loads only" geometric stiffness setting for the support structure.

Reduce the number of blade and tower mode shapes. 4 blade modes and 4 tower modes should be sufficient for most BHTM simulations. If needed these could be reduced to 2 and 2, or as a last resort flexibility could be turned off completely.

Check with a Campbell diagram or ask control algorithm engineer as to what is appropriate (e.g. are there known instabilities if blade modes are less than 4). If control algorithm or Bladed instabilities do occur, try increasing the number of modes.

If higher modes are required and it is found that the simulation is unstable, increasing the damping on the higher frequency modes can help.

3.6 Pitch actuator

Any detailed modelling of the pitch actuator (e.g. PID responses, torque limits, bearing friction, setpoint trajectory planning) should be disabled. A simple passive response is usually appropriate for BHTM simulations. The frequency can be reduced to approximate the effect of the rate & acceleration limits that were removed.

3.7 Calculation Outputs

All Bladed Calculation Outputs can all be turned off. BHTM has its own separate mechanism for data logging and export. Blade, Tower, and Other outputs should all be None or not ticked. Note there are a few outputs that cannot be turned off and will still appear in Bladed results.

The impact of writing calculation outputs on timing is not large so while checking the performance of the simplified model it may be acceptable to have some outputs enabled.

3.8 Possible advanced settings

For Bladed versions 4.7 and earlier, some special options can be defined by entering text in the Project Info window in Bladed. The same text must be entered for both dtbladed.exe and bladedsim.dll. These options are not supported in Bladed 4.8 or later.

Reduce the number of solver iterations

```
MSTART EXTRA
NumberSolveSystemIterations 1
MEND
```

Selecting specific Blade and Tower modes of interest

If the usual simplification of modes is not adequate, it is possible to specify modes in detail in Project Info. For example, the following would exclude blade modes 5, 6, 7, 8:

```
MSTART EXTRA
NBladeModeToExclude 4
BladeModesToExclude 5 6 7 8
MEND
```

4 COMPUTER HARDWARE AND SETUP FOR REAL-TIME USE

If selecting computer hardware for best performance with BHTM, choose a machine with highest sustained clock speed not many cores. The Bladed simulation executes single-threaded, so a machine with more cores will not be any faster. Typically, a high-performance desktop workstation machine is best.

To get best real-time performance, keep the computer as clean as possible – just Windows, Bladed & BHTM, and any software needed for communication with external hardware. Software such as antivirus and Microsoft Office can dramatically impair real-time performance.

For many use cases it is not necessary to optimise the hardware and system setup as detailed above – an everyday laptop with typical business software installed will often work.