
Application note

Using ARTEMiS Compensated Stubline Damping Option

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Table 1 Document revision history

v 1.0	First version	

1. Objective

This document objective is to explain the usage of the damping feature of the new ARTEMiS Compensated Stubline model[1][2] . The ARTEMiS Compensated Stubline is Bergeron traveling wave line model, with phase couplings, that is adjusted to provide an exact one-time-step propagation delay. As a standard stubline substitution of a very short line adds spurious capacitance to the network, the Compensated Stubline also compensates for the added reactive power that it creates.

2. Software Requirement

To perform the parameter modification using the method described in this documentation, the following software is required to properly install on a computer that is used to conduct this operation.

Table 1 List of Software required

Software Names	Versions
MATLAB	R2017b

3. Introduction

The ARTEMiS Compensated Stubline (ACS) implements a 1-time-step delay distributed parameters line model with interphase couplings. The ACS is typically used to obtain equation decoupling in large grids that only contains short lines.

The use of stubline will typically increase the equivalent capacitance at the point of insertion because the underlying Bergeron line model will have an equivalent length consequent with simulation sample time. The ACS compensates this increase of reactive power by adding a corresponding shunt inductance.

In some cases, despite the correction of reactive power made by the ACS model, transient behavior can still be oscillatory, depending on usage.

The current document objective is to explain the Damping Option of the ACS model, an option that is provided to decrease some unwanted transient oscillations while using the ACS.

4. ARTEMiS Compensated Stubline Damping Basics

At the point of the measurement, the additional capacitance may cause a complex oscillatory response. However if it possible to discern a simplified single oscillation in the fault current waveform or recovery voltage to ground waveform, then that waveform may be a suitable target for damping.

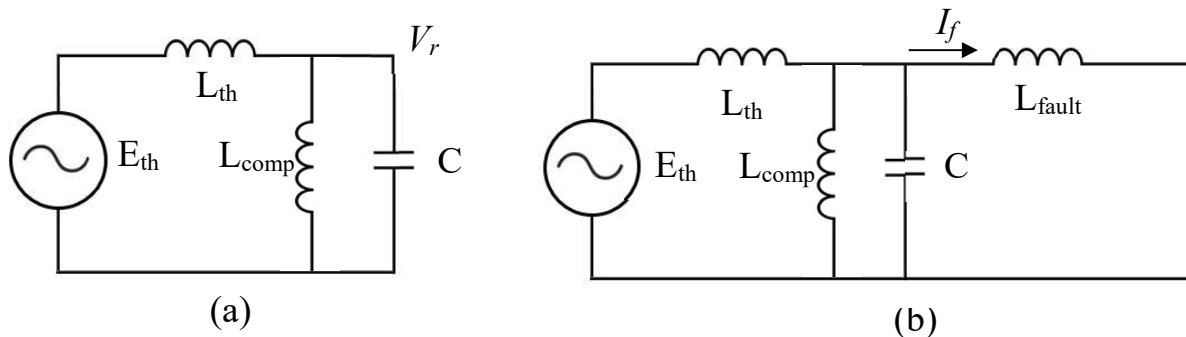


Fig 1. Simplified representations for recovery voltage (a) and faulted current (b) equivalent circuits

Fig 1. shows simplified circuits that would give rise to single frequency oscillation phase components. For the purposes of transient analysis, both circuits (a) and (b) above reduce to a simple parallel LC circuit with regards to the point of measurement. The problem then becomes how to introduce damping for the transient oscillatory component without offsetting steady-state accuracy. A possible solution is to introduce a damping resistance in parallel with the added capacitance and compensating inductance for each phase through a coupling capacitance that effectively cuts off the damping resistance at power frequency.

Fig 2. shows the added damping circuit. A rigorous analysis of the circuit [1] gives the maximum damping as $\zeta_{max} = \frac{1}{2}(\sqrt{a} - 1)$, where $a = 1 + \frac{C_{coupling}}{C}$. The resistance necessary to achieve this damping is given

as $R = \frac{a^{(\frac{3}{4})}}{\omega_0 C_{coupling}}$, where ω_0 is the observed oscillatory frequency. However, an additional constraint is that the compensating circuit (enclosed within the dashed box in Fig 2.) should appear as a single inductor L_{comp} at steady state frequency. The frequency response for the impedance of an example circuit of this type is performed and is shown in Fig. 3. If the peak of the magnitude at the frequency ω_{peak} is chosen to coincide with 100 Hz, then a phase angle of close to 90° is realized at power frequency (50 – 60 Hz), consistent with a pure inductance. In the region of transient switching frequencies (200 – 4000 Hz) the response appears to represent an RC circuit with a negative angle that becomes progressively smaller, which is appropriate for damping. It is found that selecting ω_{peak} at less than 100 gives better damping, but at the expense of departure of the steady state impedance angle from 90°. The equations necessary for design of the compensating circuit find the values for L'_{comp} , $C_{coupling}$, and $R_{damping}$ given C and L_{comp} as follows (abbreviating L'_{comp} as L'_c , $R_{damping}$ as R_d , and $C_{coupling}$ as C_c):

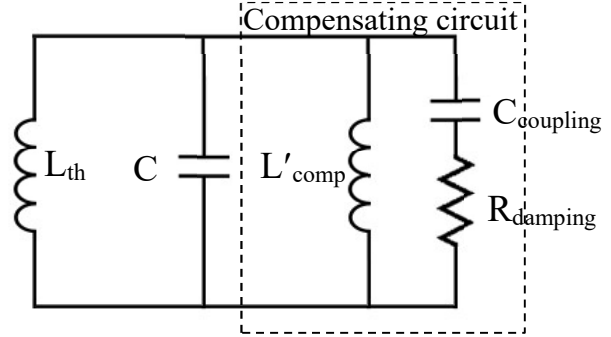


Fig 2. Adding damping to the simple LC circuit

$$L'_c C_c = (1/\omega_{peak})^2$$

$$L'_c \frac{\sqrt{(\omega_{pow} R_d C_c)^2 + 1}}{\sqrt{(\omega_{pow} R_d C_c)^2 + (\omega_{pow}^2 L'_c C_c - 1)^2}} = L_{comp}$$

$$R_d = \frac{a^{(\frac{3}{4})}}{\omega_0 C_c}$$

Where

- ω_{pow} = power frequency (= $2\pi f_{pow}$)
- ω_0 = observed oscillatory frequency
- ω_{peak} = peak magnitude frequency (= $2\pi f_{peak}$, where f_{peak} is typically 80 - 100 Hz)

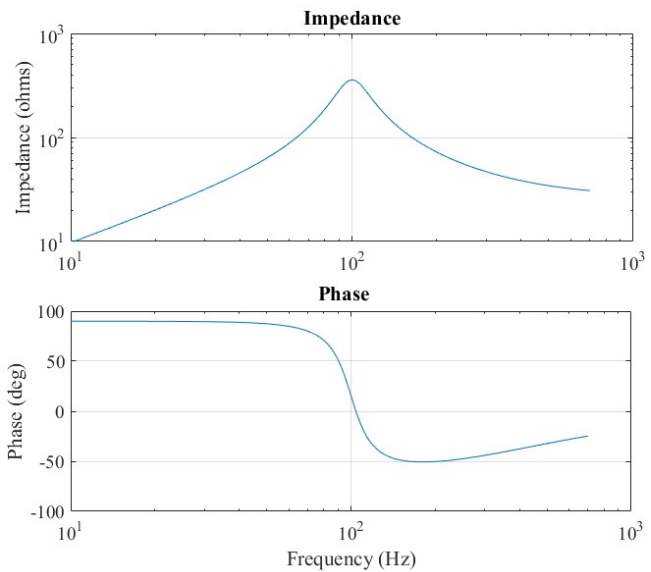


Fig 3. Frequency characteristics of the compensating circuit

The three equations are solved numerically, all non-real solutions are discarded, and the real solution which offers L'_{comp} as close as possible to L_{comp} is selected.

5. Usage examples

In this section, we will explain the usage of the ACS damping option, with benefits and drawbacks, on 2 demo models: IEEE 13 node test feeder and IEEE 123 node test feeder. The original demos are available in the ARTEMiS help section.

5.1 IEEE 13 node test feeder

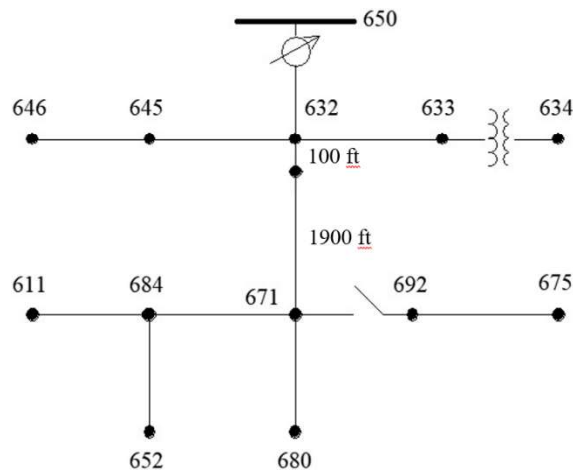


Fig 4. IEEE 13 node feeder diagram with line 632-671 divided into two segments

In the ARTEMiS help section, the IEEE 13 node system was used to demonstrate the novel decoupling method of the Compensated Stubline. In this application note, we will use the system again to demonstrate the Compensated Stubline with the damping option. However, the original line used for decoupling between nodes 632 and 671 is too long at 2000 ft for the added capacitance to make an appreciable effect on dynamics. We thus make the decoupling line much shorter by dividing the lines into two segments of lengths 1900 ft and 100 ft as shown in Fig 4.0. The shorter 100 ft segment is used for decoupling.

A line to ground fault on phase (b) at bus 671 is applied for 3 cycles and removed. Using the ARTEMiS-based SSN solver with Compensated Stubline decoupling will lead to observed oscillations on the incipient fault-current waveform. The original SPS solution for the complete system does not contain these oscillations – therefore they are attributed to the effect of the large capacitance required to implement Stubline decoupling for the 100 ft line segment. The oscillations are very lightly damped and have frequency of around 1600 Hz.

To attempt damping these oscillations according to the theory discussed in section 4.0, the mask of the Compensated Stubline has the option to include damping as shown in Fig 5. The user will check the box <Damping required?> and is then presented with the option for entering the observed <Undamped Frequency> and <Peak Frequency> (ω_{peak}), which has a default of 100 Hz.

Upon entering the values and hitting the <Apply> button, the corresponding compensation block must be updated (using <Update stub compensation block>). A look under the mask of the compensation block (Fig 6.) reveals the damping resistors in series with coupling capacitors on all phases.

For the IEEE 13 node system, damping was implemented as described above. Fig 7. presents the waveforms of the incipient fault current for three simulations: (1) SPS-based intact system, (2) SSN-based decoupled system using a 3-phase Coupled Stubline (2 modes), and (3) Same SSN-based system in (2), but with the damping option selected and implemented. The damped waveforms (shown dashed) are seen to quickly settle down to the path of the original waveform.

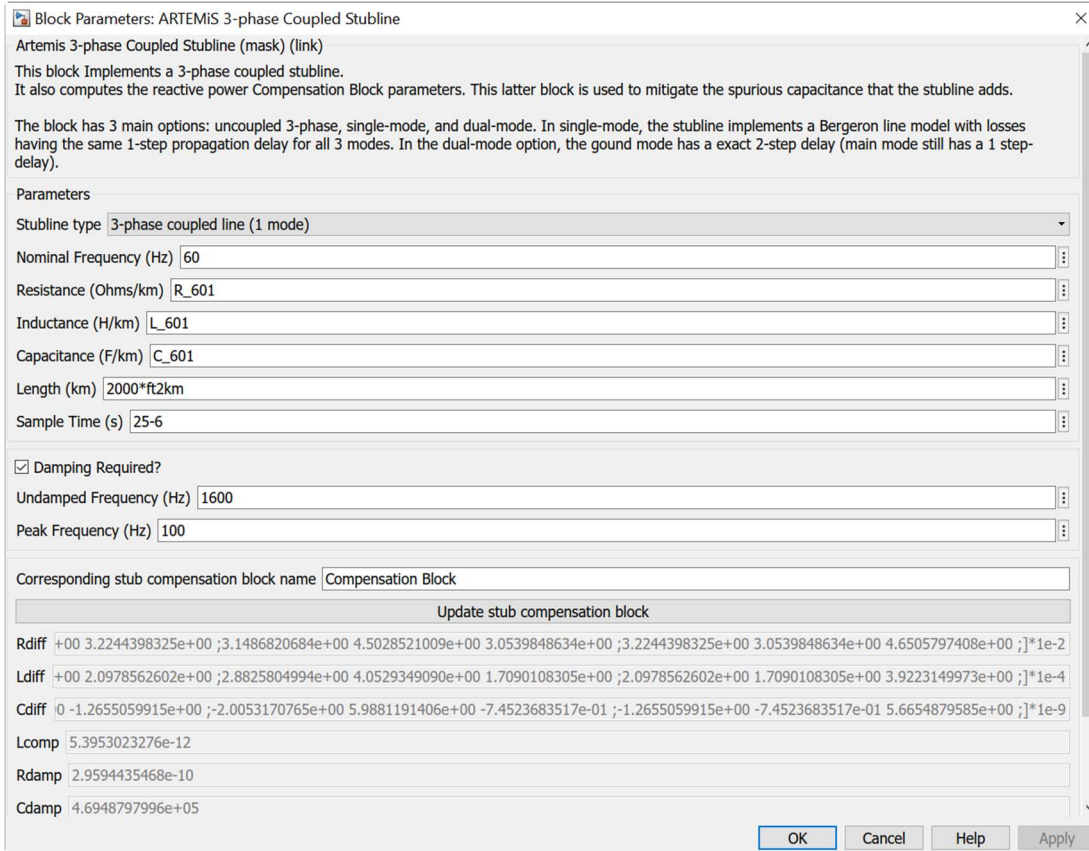


Fig 5. ARTEMiS 3-phase Coupled Stubline mask with ‘Damping’ option

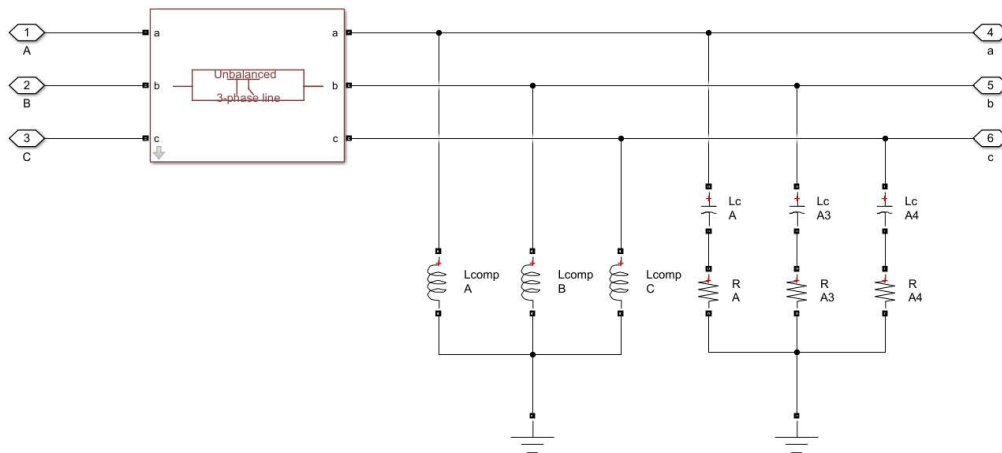


Fig 6. Looking under the mask of the ARTEMiS 3-phase Coupled Stubline Compensation Block

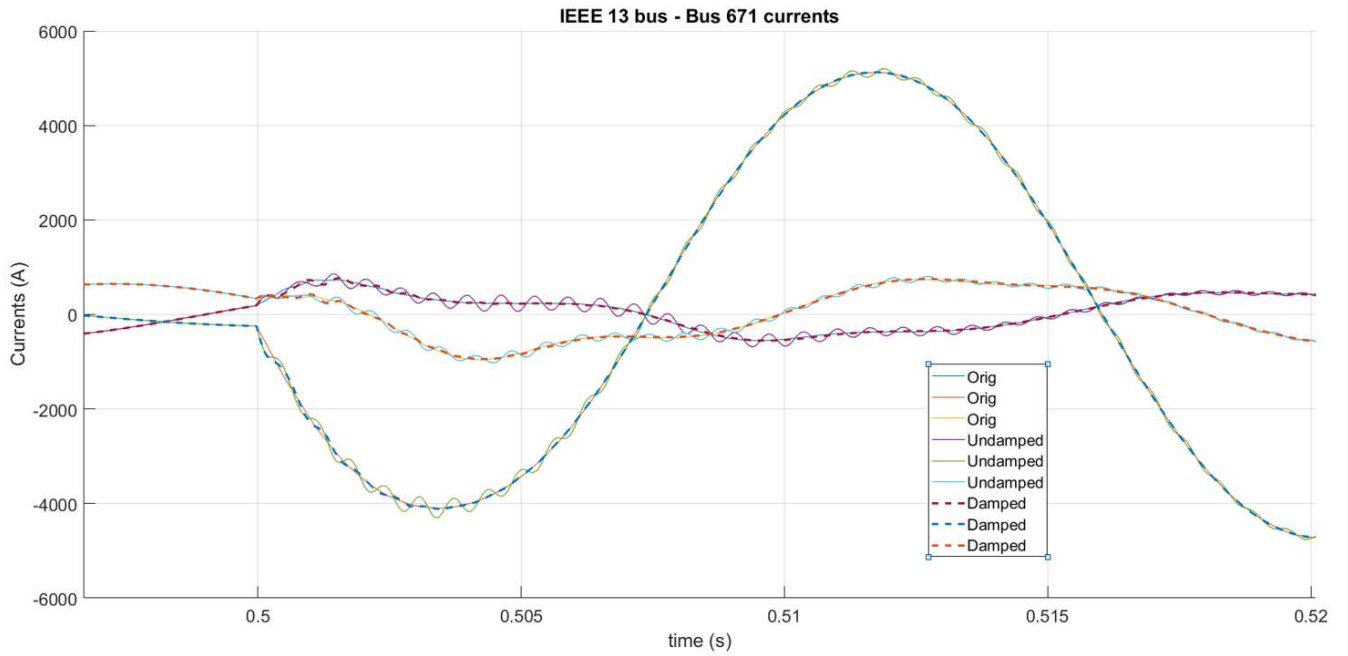


Fig 7. Line – Ground fault on bus 671 of the IEEE 13 bus system; Original, Undamped and Damped simulations

5.2 IEEE 123 node test feeder.

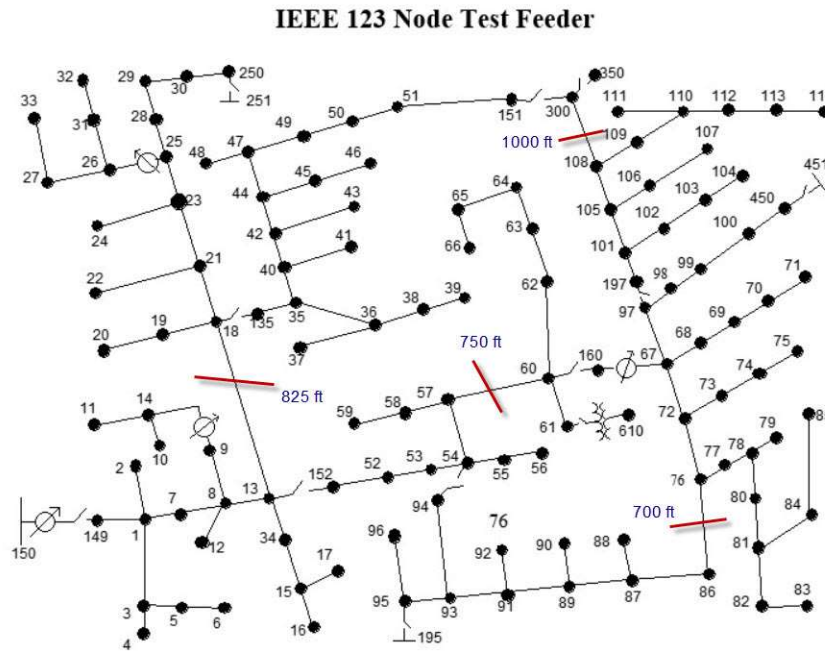


Fig 8. IEEE 123 node test feeder diagram with ACS locations

Fig. 8 shows ARTEMiS Compensated Stubline locations for the IEEE 123 node test feeder. In this model, no modifications are made to demonstrate the need for oscillation damping, since the line are already short (ranging from 700 and 1000 ft) and decoupling will introduce some oscillatory behaviour. A comparison is made between an SPS-based simulation for the complete system for a line–line fault (phase's b & c) at bus 23 and an SSN-decoupled simulation for the same fault. The fault is applied for 3 cycles and when removed transient oscillatory behaviour in the recovery voltage appear in the SSN simulation as shown in Fig. 9. The incipient fault current also shows brief oscillations, but they are mostly insignificant. Both simulations are solved with the Backward Euler method and no damping is applied in the ACS decoupling lines compensation blocks.

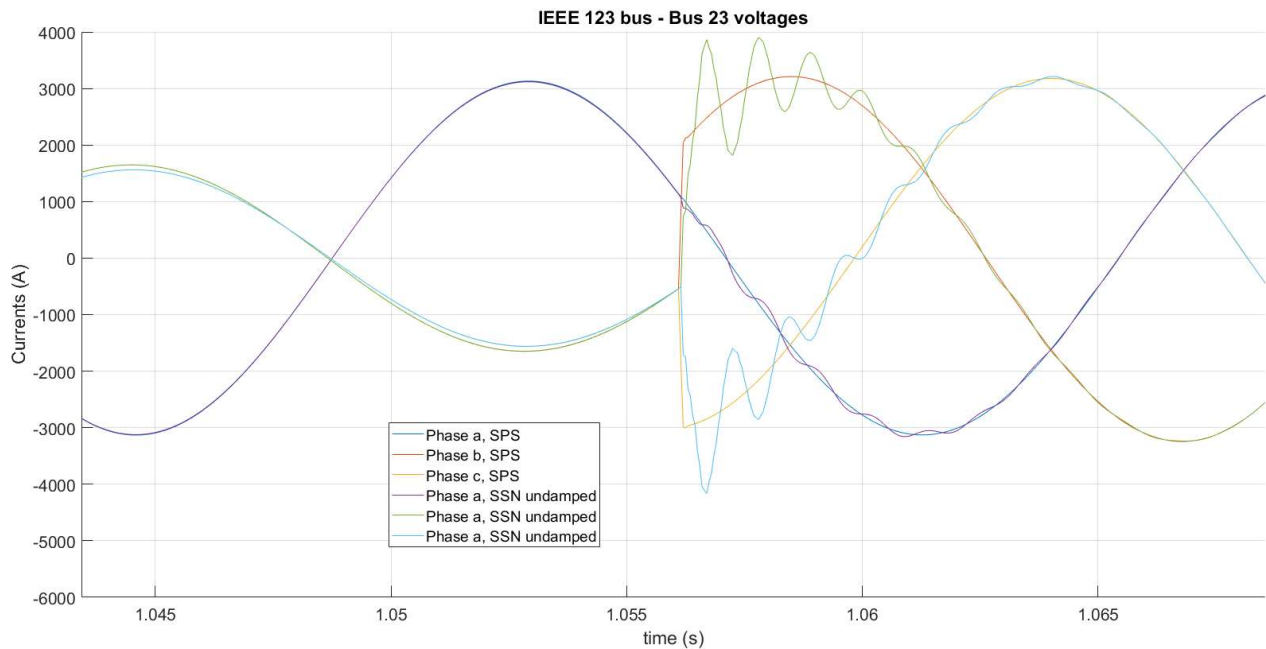


Fig 9. IEEE 123 node voltage recovery waveforms – SPS-based and SSN undamped.

It is possible to reduce these oscillations by selecting the damping option in the ARTEMiS Compensated Stublines and entering relevant damping information. The observed oscillation has a frequency around 900 Hz, and with the default value of $\omega_{peak}=100$ Hz, the oscillation damping improves. Reducing the values of ω_{peak} improves damping further, and Fig 10. shows resulting waveforms for values of ω_{peak} of 100, 80, and 70 Hz. The best damping is seen with $\omega_{peak}=70$ Hz, shown dotted. The problem with reduction of ω_{peak} even further is that it leads to the departure of the compensating block from presenting a pure shunt inductance under steady-state (power frequency) conditions, at it should do. The angles of the shunt component in the compensating block corresponding to the values of ω_{peak} above for the first decoupling line (between bus 13 and 18) are 87°, 81° and 67° under steady state conditions. If ω_{peak} is set equal to the power frequency (60 Hz for this system) the angle goes all the way down to about 13°, resulting in a largely resistive component instead of inductive. This will lead to inaccurate steady-state conditions.

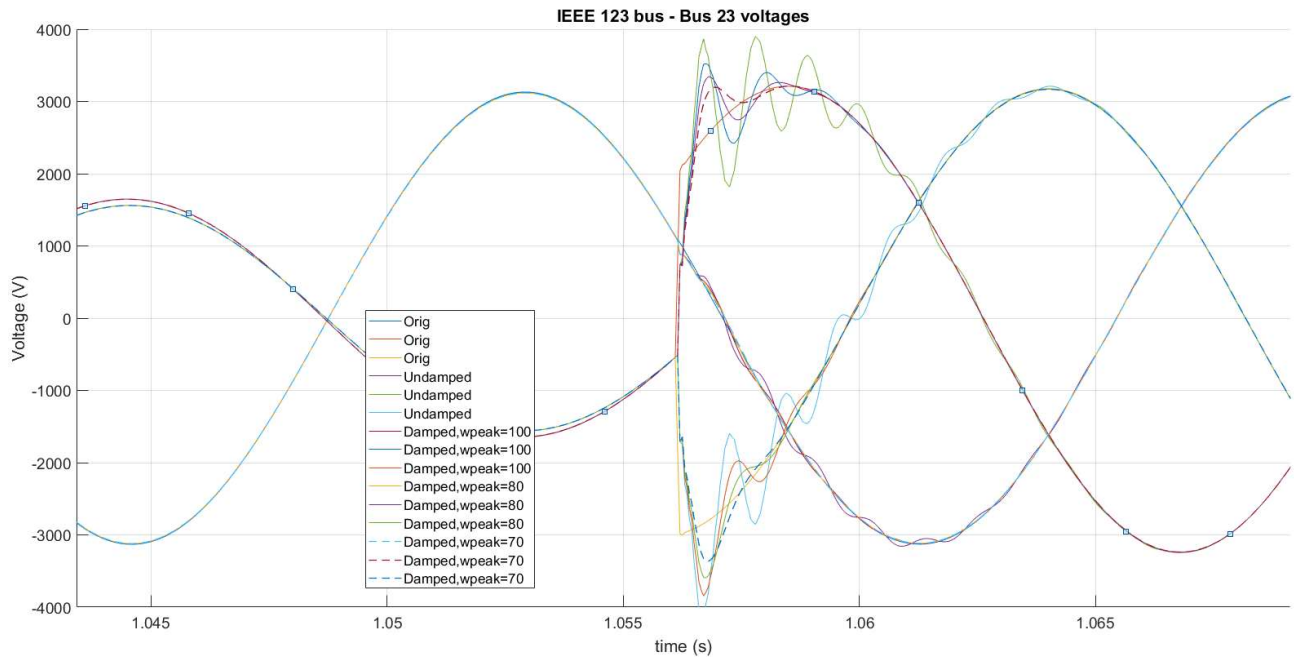


Fig 10. IEEE 123 node voltage recovery waveforms – different values for ω_{peak}

6. References

- [1] B. Ahmed, A. Abdelgadir, N. Saied and A. Karrar, "A Compensated Distributed-Parameter Line Decoupling Approach for Real Time Applications," in IEEE Transactions on Smart Grid, doi: 10.1109/TSG.2020.3033145..
- [2] C. Dufour, J. Mahseredjian, J. Bélanger, J. L. Naredo, "An Advanced Real-Time Electro-Magnetic Simulator for Power Systems with a Simultaneous State-Space Nodal Solver", IEEE/PES T&D 2010 - Latin America, São Paulo, Brazil, Nov. 8-10, 2010