Western Electricity Coordinating Council
Modeling and Validation Work Group

Pseudo Governor Model for Type 1 and 2 Generic Turbines

Prepared by
WECC Renewable Energy Modeling Task Force

October 2012

This work is supported by Sandia National Laboratories and the
US Department of Energy under Sandia Contract #1257843.

Background

The Renewable Energy Task Force (REMTF) of the Western Electricity Coordinating Council (WECC) developed a suite of generic models appropriate to represent wind power plants in bulk transmission studies. These models are non-proprietary and can be used to represent wind turbine-generators (WTGs) with similar physical and control topology, by adjusting model parameters depending on the specific WTG manufacture and controls. The phase 1 models have been available in commercial simulation programs for several years. REMTF has initiated a Phase 2 wind power plant modeling effort with the purpose of improving all the generic models, in consultation with manufacturers and other stakeholders. This work is coordinated Sandia National Laboratories (SNL), on behalf of the Department of Energy (DOE).

The existing Phase 1 generic models were developed based on limited knowledge of specific manufacture's wind turbines controls. User experience indicates that the existing pseudo governor model for type 1 and 2 wind turbines does not represent very well the effect of pitch control in some manufacture's turbine behaviors. Specifically, the model does not capture control strategy when the wind turbine is exposed to a severe low voltage condition. EnerNex was asked by Sandiato modify the pseudo governor model of type 1 and 2 generic turbine models to represent more accurately the effect of pitch control action different manufacture's wind turbine-generators.

Current Pseudo Governor Model

The existing pseudo governor model for type 1 and 2 wind turbines (see Figure 1) produces the mechanical power, which is the output to the generic wind turbine model, based on the generator speed and active power.

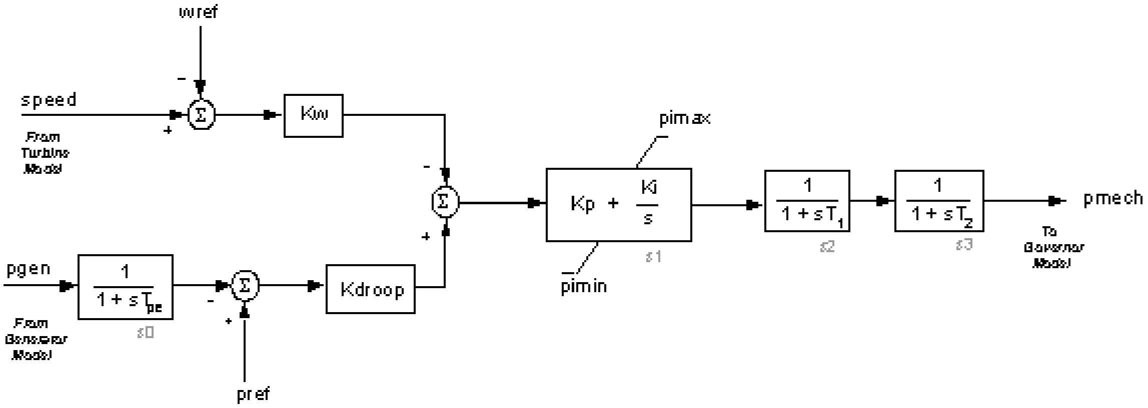

Figure 1 Diagram of existing pseudogovernor model

This control scheme may cause some problems under certain circumstances. During a simulated scenario that involves a sustained frequency excursion, the existing pseudogovernor model would produce a sustained increase in mechanical power from the turbine. For a fixed wind speed, this type of response is not expected from a WTG.

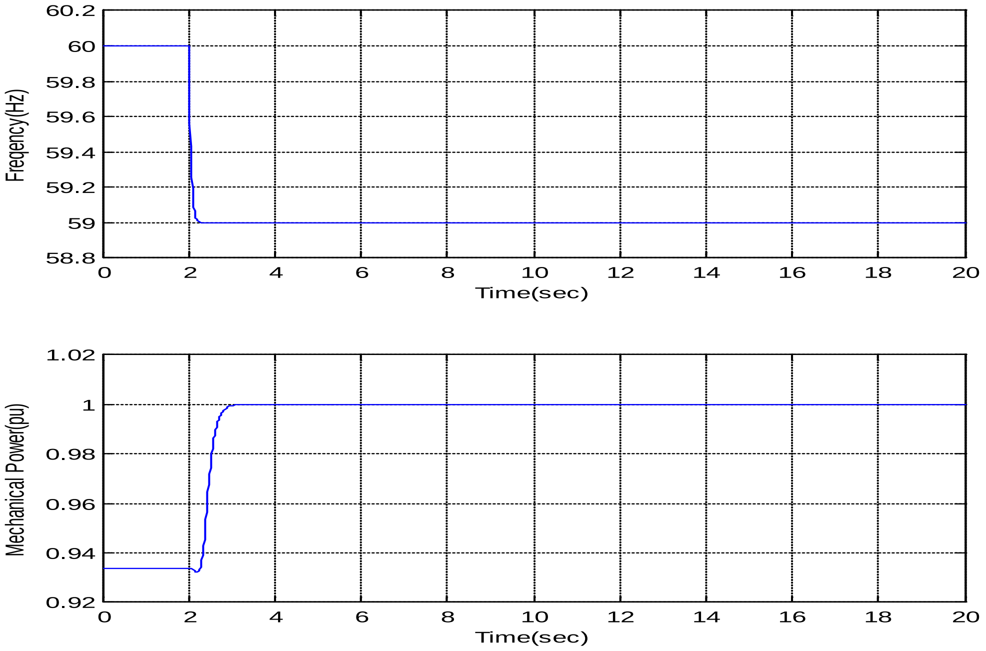

Figure 1 Behavior of the existing pseudo governor model during frequency decrease

Pseudo Governor Model Structure

Pseudo governor model is to produce the mechanic power, which is the function of the pitch controller and aerodynamic model of vendor specific models. During a low voltage condition, the generator power delivered to the grid can decrease sharply, and the speed of the turbine begins to increase. Depending on the severity of the fault, the machine may trip or negatively affect transient recovery after fault clearing, unless control action is taken. The general strategy used in pitch-controled Type 1 and Type 2 WTGs is to rapidly reduce aerodynamic power by pitching the blades. By observing the behavior of a common Type 1 and a common Type 2 WTG deployed in North America (Mitsubishi MWT1000A and Vestas V82, respectively. These two are widely used type 1 and 2 wind turinbesin North America), it can be seen that, following the detection of a low voltage condition, the mechanical power drops to a certain level and then it starts to rise after grid voltage has recovered. To mimic this behavior, a structure of the pseudo governor is proposed and is shown in Figure 2. When a fault happens and the terminal voltage is below a certain threshold, the Flag is set to 1, and this Flag signal switches the

the reference power from P0 (initial power) to Pmin (a pre-determined power level less than P0). The mechanical power will keep droping according to the PI and rate limit control. After a certain time, the Flag signal resets and the reference power switches to P0 and the mechanical power starts to rise.

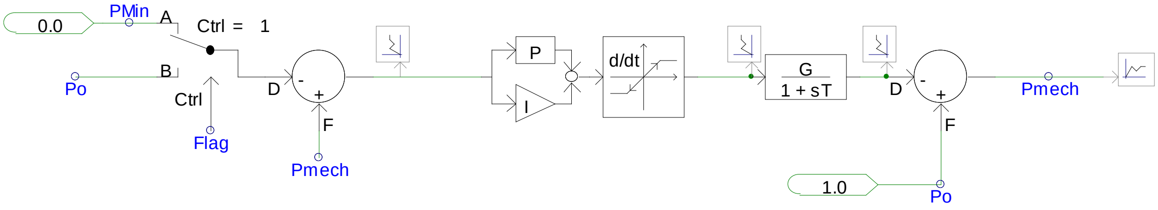

Figure 2 Pseudo governor model structure

Logic to Set the Flag

The logic setting the Flag and associated timers was developed based on the control strategy represented in two manufacturer-specific WTG models. For the V82 model, a series of simulations were conducted on the manufacturer-specific model, for terminal voltage drop of 0.0, 0.6 and 0.8 pu. The terminal voltages and mechanical power are shown in

Figure 3 and Figure 4. The simulations shown were conducted at rated power output. For different voltage drop levels, the mechanical power drops to different levels and the time to reach the minimum value varies. Additional simulations were conducted at different output levels. The results indicate that the mechanical power changes significantly only if the electrical power of a single turbine is larger than 0.91 per unit (i.e. approximately 1.65 MW, based on the machine MVA base of 1.808 MVA). Figure 5 shows the terminal voltage and mechanical power output of V82 when the voltage drops to 0 per unit and the power level is 0.7 per unit.

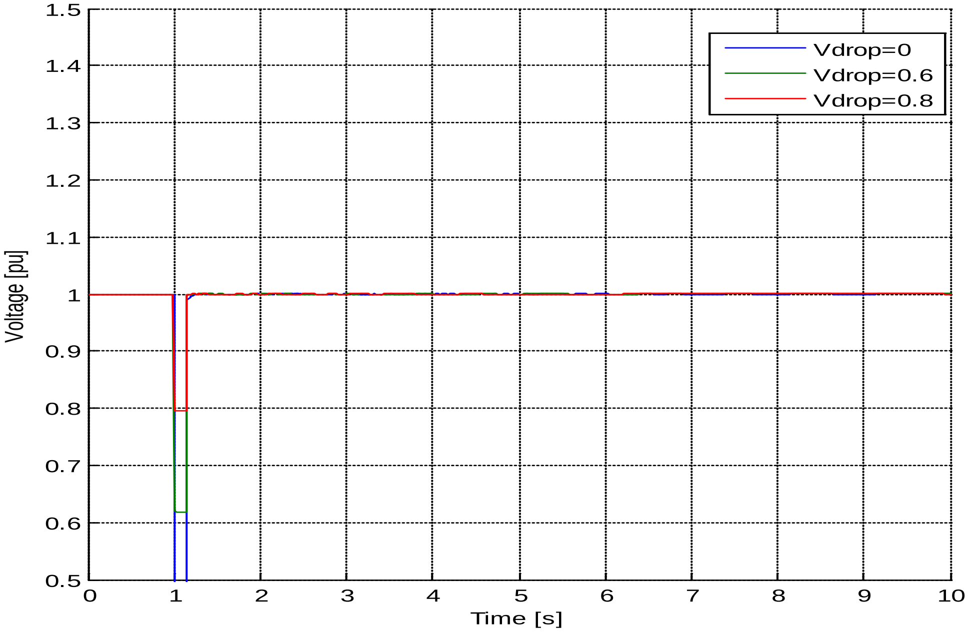

Figure 3 Terminal voltage of V82 detailed model when the fault voltage drops to 0.0, 0.6 and 0.8 per unit, respectively

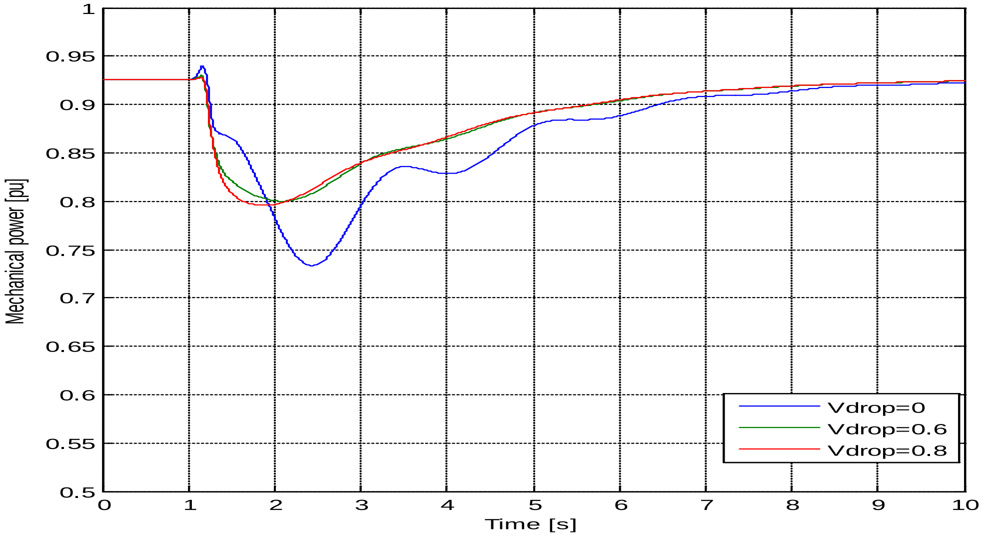

Figure 4 Mechanical power output of V82 detailed model when the fault voltage drops to 0.0, 0.6 and 0.8 per unit, respectively

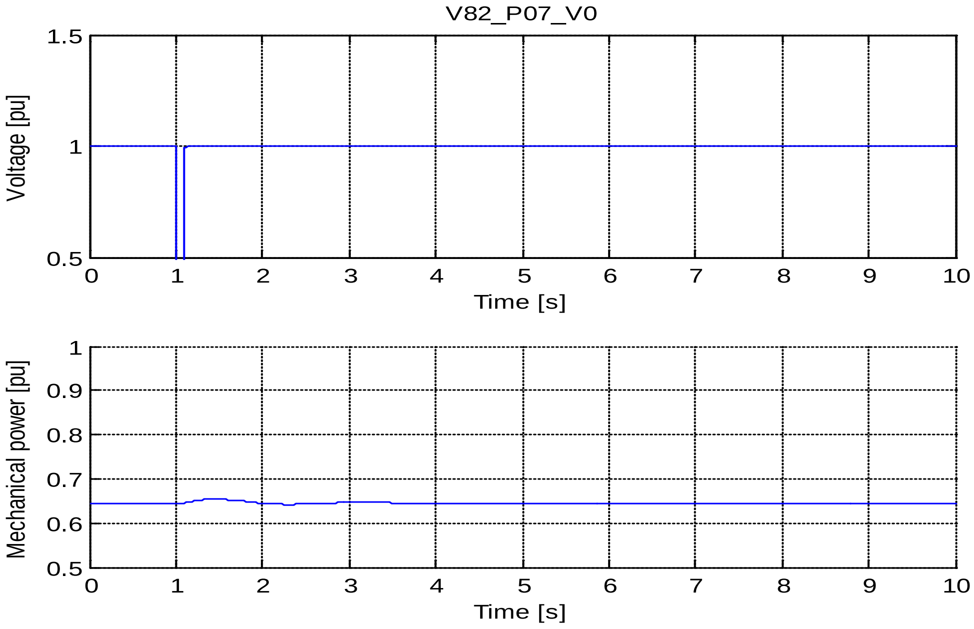

Figure 5 Terminal Voltage and mechanical power output of V82 detailed model when the fault voltage drops to 0 per unit and power equals to 0.7 per unit

Based on the simulations, the relationship between the maximum generator speed increase (Δω) and the time to reach the minimum mechanical power (T) is approximately linear, as follows: (T=kΔω+b). When the time after a fault is larger than T, the "Flag" switches to zero, the mechanical power reference switches from Pmin to P0, and mechanical power starts to rise.

A similar set of simulations were conducted using the manufacturer-specific model for the Mitsubishi MWT1000A wind turbine-generator. The behavior of the mechanical power when the fault voltage drops to different levels (i.e. 0, 0.3, 0.6 and 0.8 per unit) is shown in Figure 6. Two points can be made from these simulations: First, the mechanical power does not change significantly when the voltage does not drop below 0.6 per unit. Second, the time to reach the minimu mechanical power after a fault does not change significantly for voltage drop to 0 per unit and 0.3 per unit. To mimic these characteristics using the proposed model shown in Figure 2, the Flag signal needs to be set to 1 only when the voltage drop is below 0.6 per unit. When the voltage does not drop below 0.6 per unit, the Flag singal does not change and P0 (constant) remains the mechanical power reference. For this turbine, the time to reach the minimum mechanical power is not a function of speed. To make the time to reach the minimum mechanical power after a fault constant, the k value of the linear curve just needs to be set to 0.

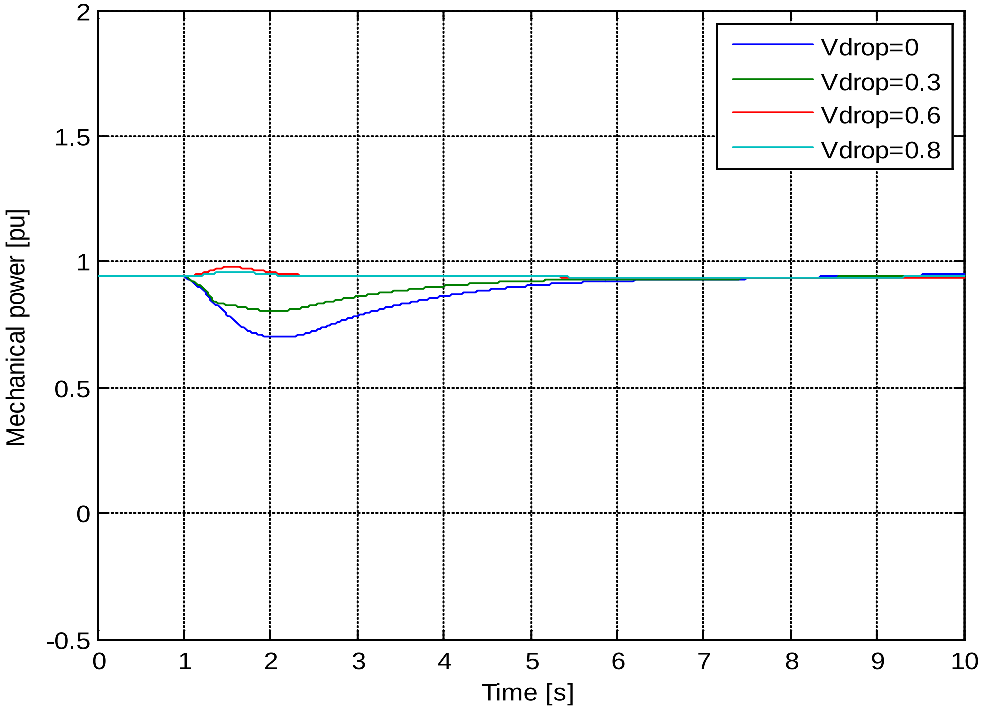

Figure 6 Mechanical power output of MWT1000A detailed model when the fault voltage drops to 0.0, 0.3, 0.6 and 0.8 per unit, respectively

Based on the observations described above, the logic to control the Flag signal can be represented as shown in Figure 7. When the voltage magnitude is less than the voltage setting (Vdip), and the Flag signal is equal to 0, the Flag signal is set to 1 and the time is stored in the variable Tf. If the wind turbine's prefault electrical power is larger than the power setting (Pset), the maximum generator speed within b seconds (b is the intercept in the linear equation $T=k\Delta\omega+b$) is found. Based on the maximum generator speed increase, the time to reach the minimum mechanical power after a fault, Timer, is calculated. When the simulation time is larger than Tf+Timer, the Flag signal is set to 0 and Tf is set to 9999.0.

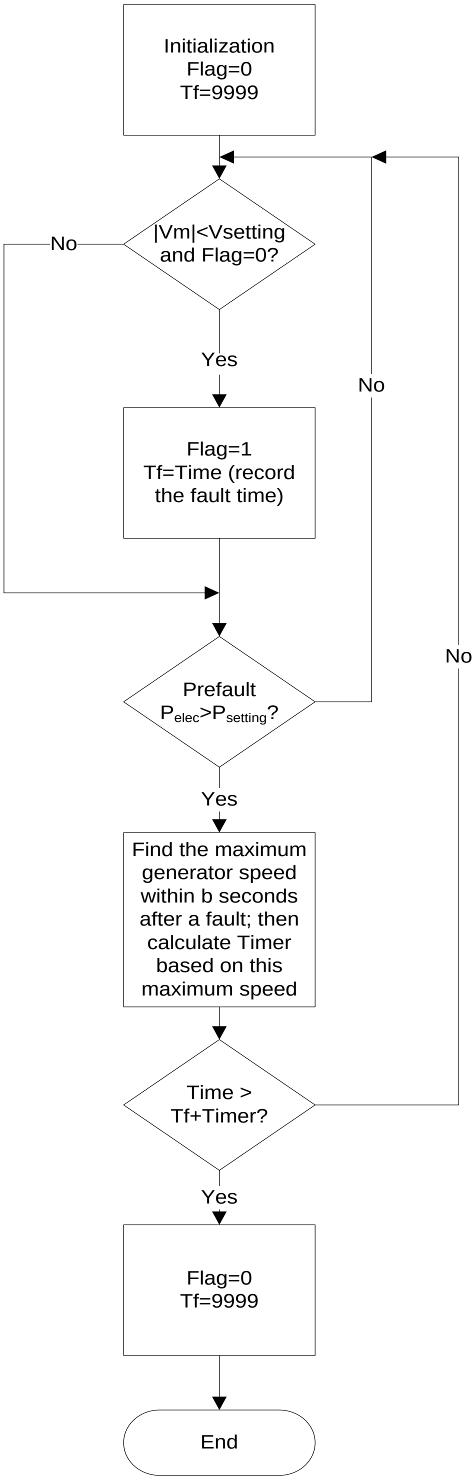

Figure 7 Logic to control the Flag signal

Parameterization of Vestas V82

By doing the simulations, it was found that the mechanical power of the turbine will change significantly only when the prefault active power is 1.65 MW, so Psetting is set as 0.9126 per unit (=1.65 MW/1.808 MVA). The voltage setting Vdip is set as 0.85 per unit. From simulations, the values of the generator speed increase and the time to reach the minimum mechanical power after a fault are listed in Table 1. By doing a linear curve fitting, the parameters k and b are obtained and they are 9.9732 and 0.8738, respectively. Other parameters in the pseudo governor model are obtained by tests. The values of all parameters are shown in Table 2.

Table 1: Values of the generator increase and the time to reach the minimum mechanical power after a fault

Generator increase (per unit)	Time to reach the minimum mechanical power after a fault (sec)
0.0055	0.8335
0.0132	1.0738
0.0311	1.2474
0.0639	1.4744

Table 2: Parameters for V82

Parameter	Description	Value
G	Gain for the first order delay	0.3
Td	Time constant for the first order delay	0.5
Kp	Proportional gain for the PI controller	0.8
Ti	Time constant for the PI controller	0.01
Rmax	Maximum rate limit for the PI controller	0.3
Rmin	Minimum rate limit for the PI controller	0.1
Pmin	Minimum power	0.3
Vdip	Voltage setting	0.85
Psetting	Power setting	0.9126
Kt	Slope of the fitting curve	9.9732
bt	Intercept of the fitting curve	0.8738

Parameterization of MWT1000A

Through simulations, the power setting Psetting is set to 0.9 per unit. If the power is lower than 0.9 per unit, the change of the mechanical power is not significant. The voltage setting Vdip is set to 0.6 per unit, so that if the voltage drop during a fault is above 0.6 per unit, the mechanical power won't change. This value is obtained by observing the simulation results of the detailed model. As mentioned in a previous section, the time to reach the minimum mechanical power after a fault for MWT1000A does not change significantly for different voltage drop levels. Therefore, the slope of the fitting curve k is set to 0 and the intercept of the fitting curve is set to a constant, 0.8. Therefore, the mechanical power will reach the minimum value at 0.8 second after a fault. Other parameters in the pseudo governor model are obtained by tests. The values of all parameters are shown in Table 3.

Table 3: Parameters for MWT1000A

Parameter	Description	Value
G	Gain for the first order delay	1.5
Td	Time constant for the first order delay	5.0
Kp	Proportional gain for the PI controller	1.0
Ti	Time constant for the PI controller	1.0
Rmax	Maximum rate limit for the PI controller	0.5
Rmin	Minimum rate limit for the PI controller	0.3
Pmin	Minimum power	0.0
Vsch	Voltage setting	0.6
Psch	Power setting	0.9
Kt	Slope of the fitting curve	0.0
bt	Intercept of the fitting curve	0.8

Simulation Results

Some simulations are done to compare the behavior of the generic model with the new pseudo governor model and the vendor specific (detailed) models. The results are shown in Figure A1-Figure A30(Appendix A)

Application of New Pseudo Governor Model to a Frequency Excursion Case

As shown in Figure 1, the current pseudo governor model has issues during a frequency excursion case. More plots of this model are shown in Figure 8 and Figure 9. It can be seen that with the step down of the frequency, the WTG terminal voltage increases and the speed decreases. The WTG produces more active power and absorbs more reactive power.

The same plots are shown in Figure 10 and Figure 11 for the new pseudo governor model. Since the mechanical power of the new pseudo governor model dose not change with the system frequency (as shown in Figure 12), the change of the WTG terminal voltage, active power and reactive power are much less significant than those of the existing pseudo governor model.

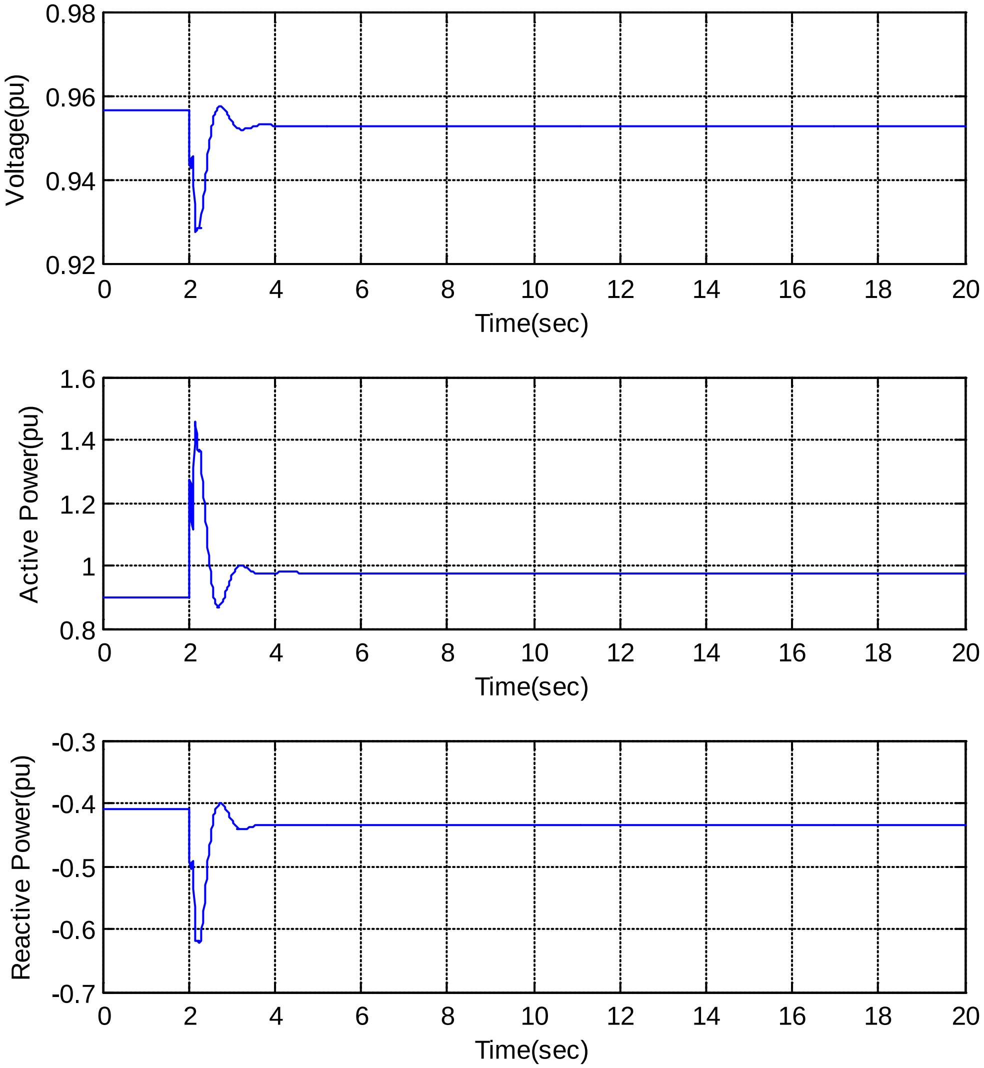

Figure 8 Voltage and power behavior of WTG using the existing pseudo governor model

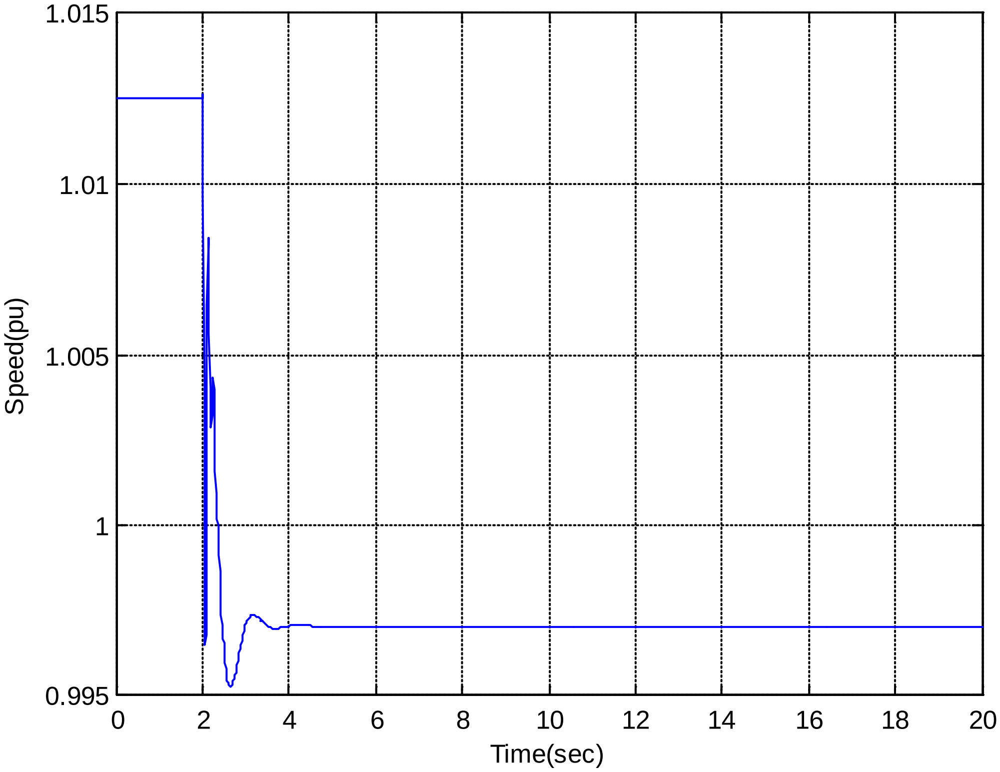

Figure 9 Generator speed of WTG using the existing pseudo governor model

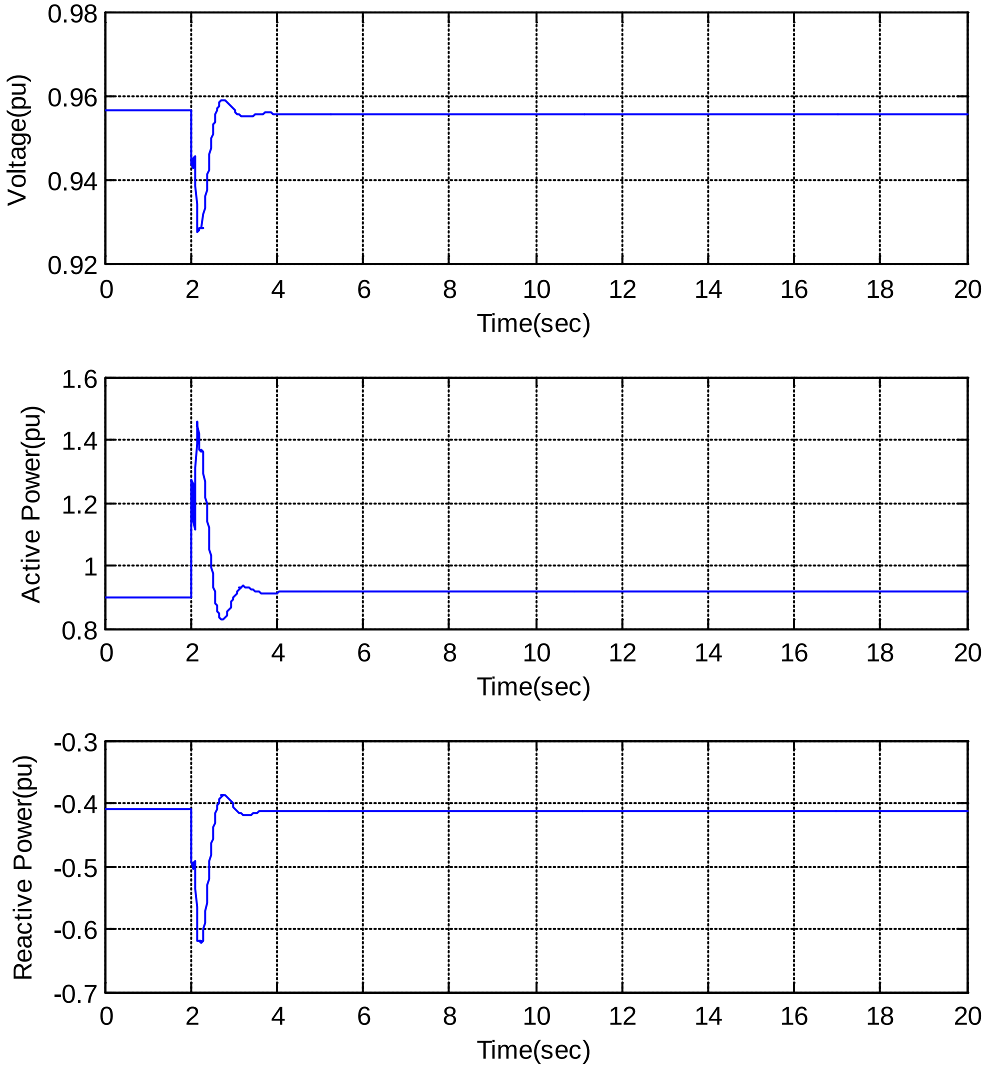

Figure 10 Voltage and power behavior of WTG using the new pseudo governor model

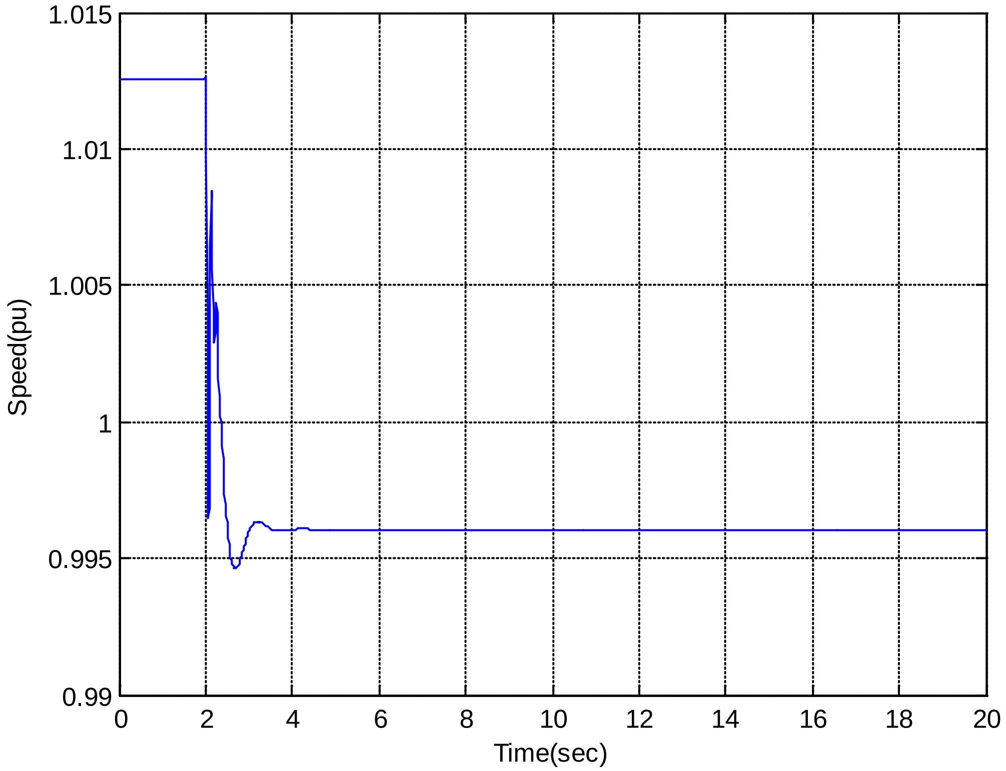

Figure 11 Generator speed of WTG using the new pseudo governor model

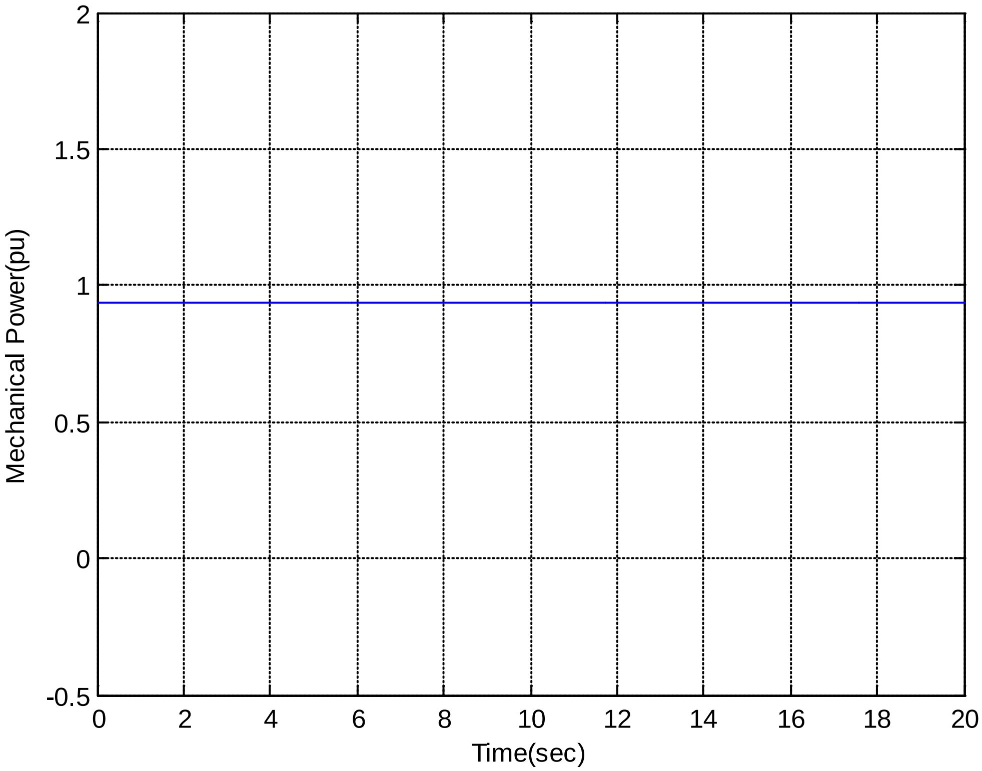

Figure 12 Generator mechanical power of WTG using the new pseudo governor model

Conclusion

From these simulation results, it can be seen with proper tuning the parameters, the proposed model appears to be acceptable based on limited verification with some vendor specific model. The new model has a better behavior during frequency excursions than the existing model.

References

[1] WECC Renewable Energy Modeling Task Force, "WECC Wind Power Plant Model Dynamic Reference Guide," August 2010

[2] Siemens PTI, "PSSE 31.0 user manual," December 2007

[3] General Electric, "PSLF 17 user manual," April 2010

Appendix A

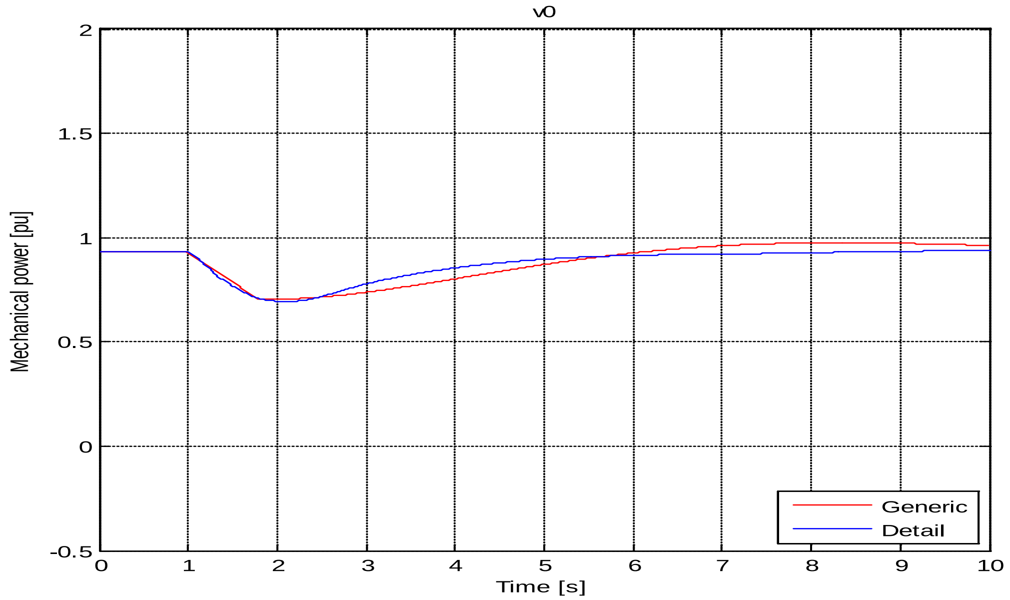

Figure A1 Mechanical power output of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0 per unit

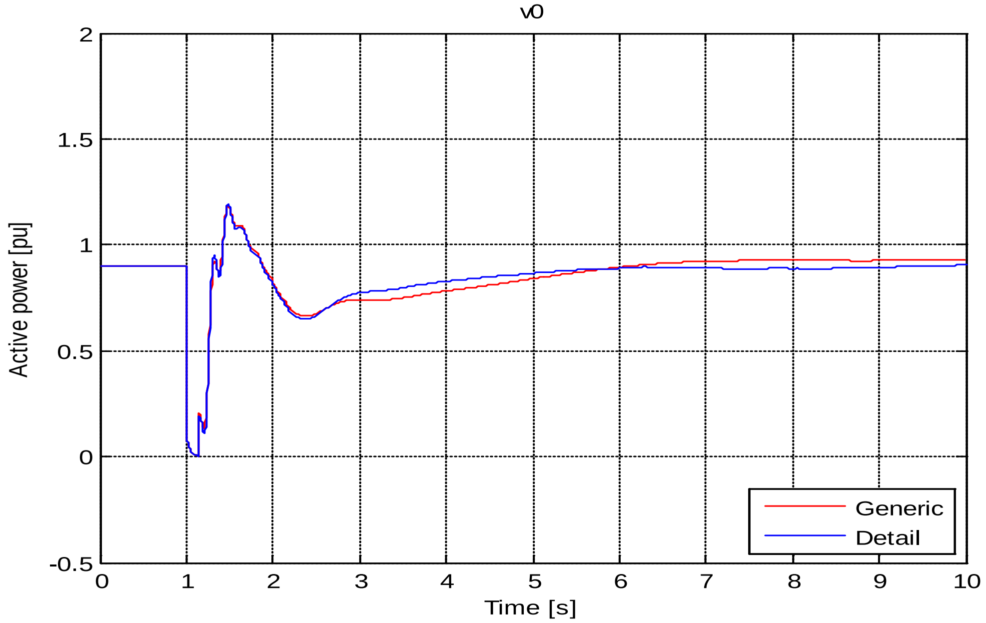

Figure A2 Active power output of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0 per unit

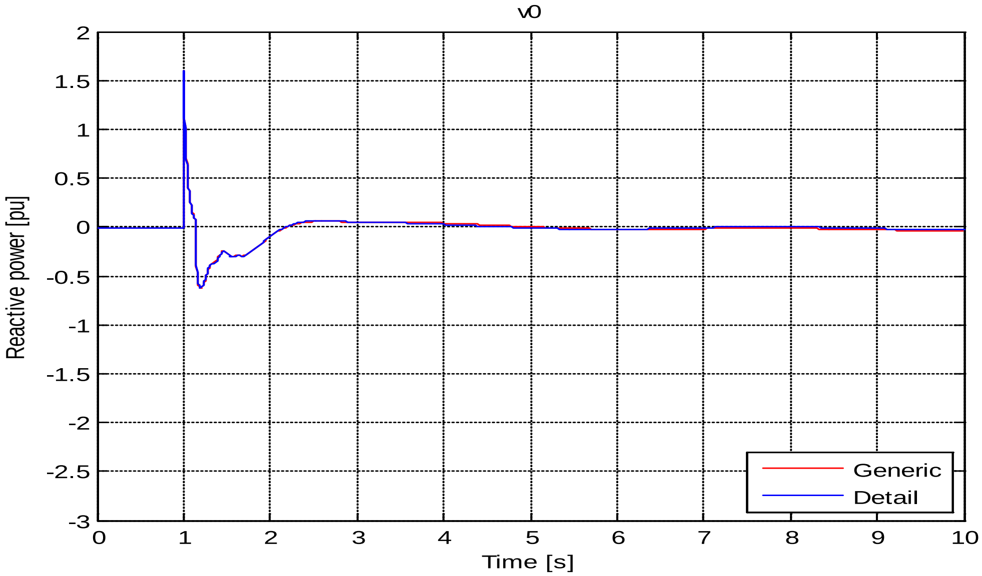

Figure A3 Reactive power output of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0 per unit

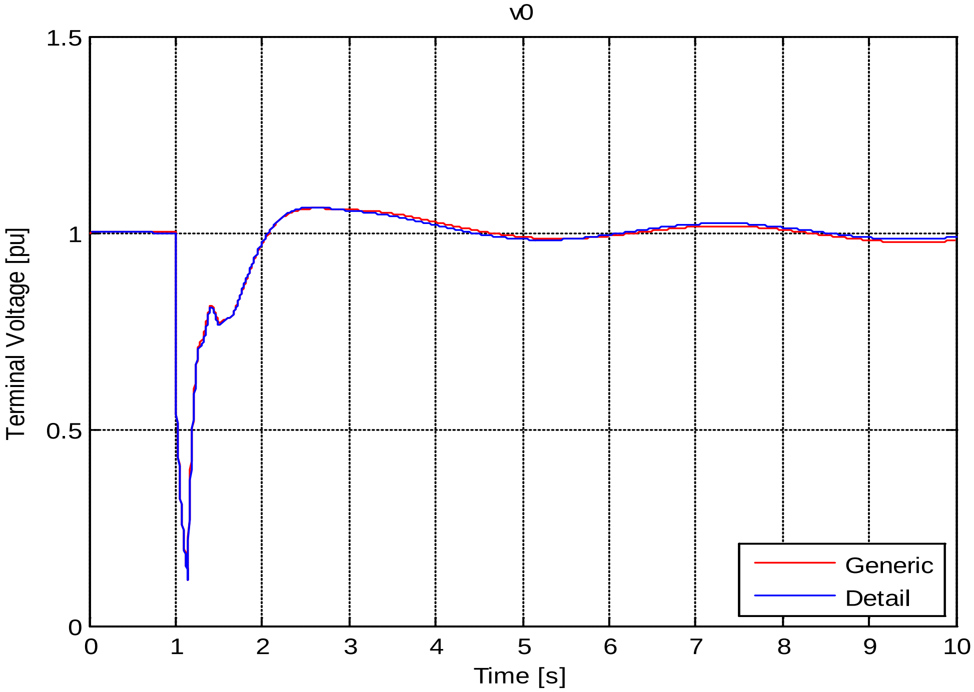

Figure A4 Terminal voltage of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0 per unit

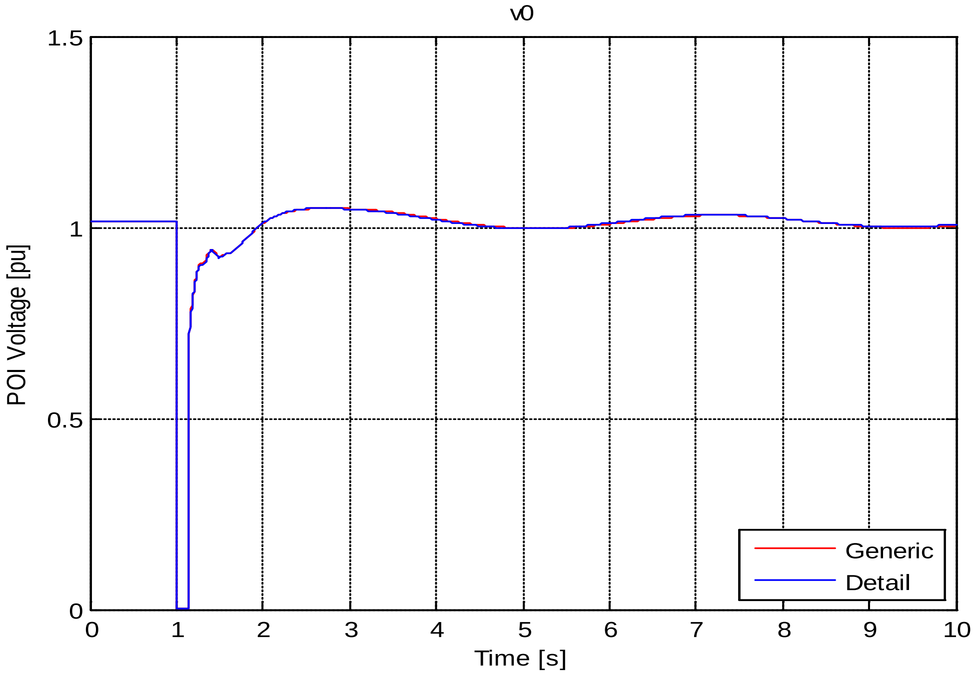

Figure A5 POI voltage of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0 per unit

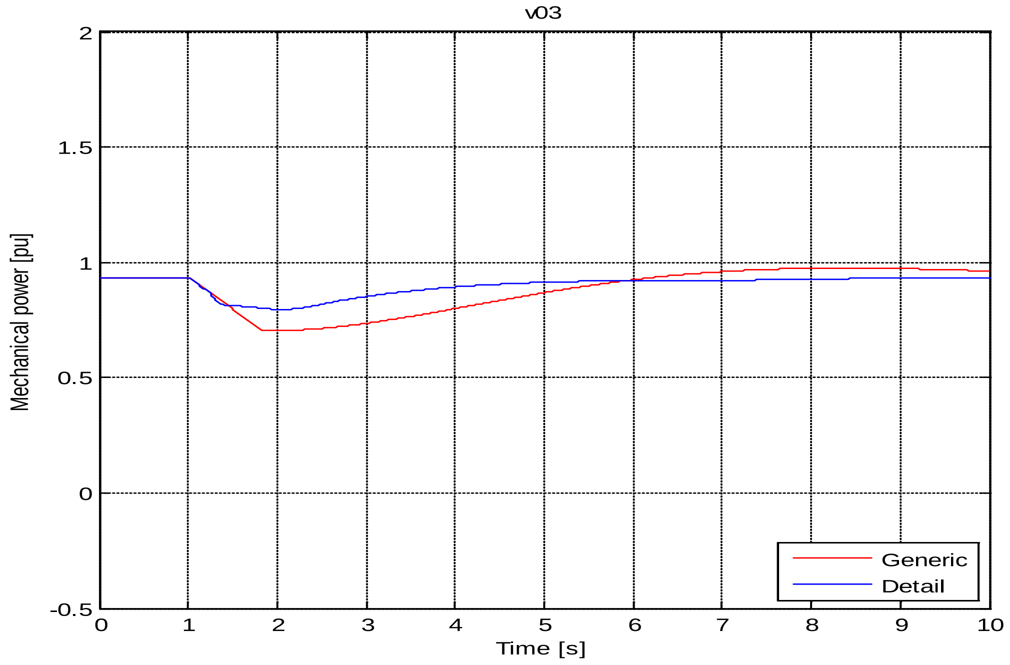

Figure A6 Mechanical power output of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.3 per unit

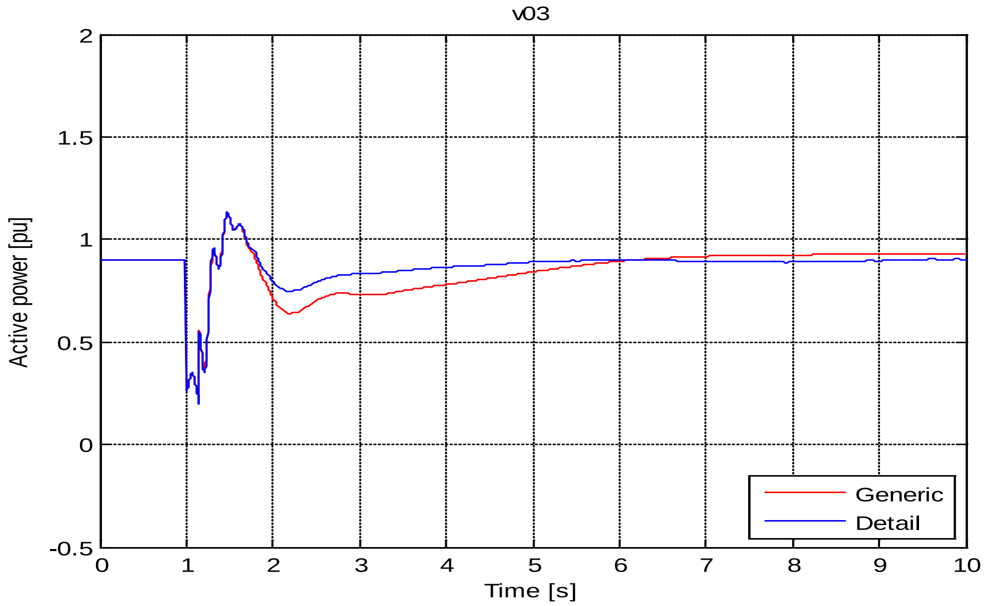

Figure A7 Active power output of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.3 per unit

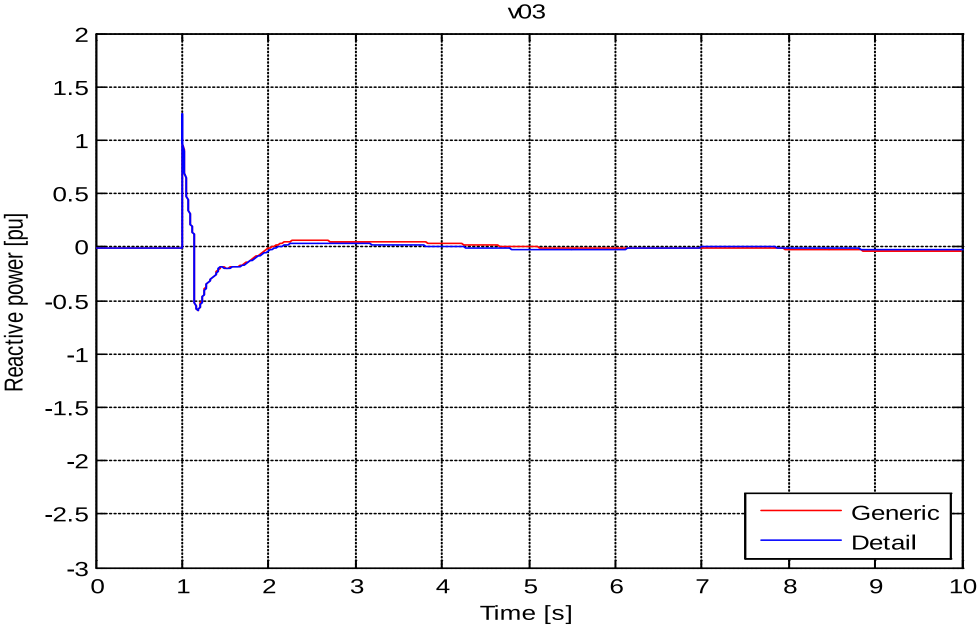

Figure A8 Reactive power output of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.3 per unit

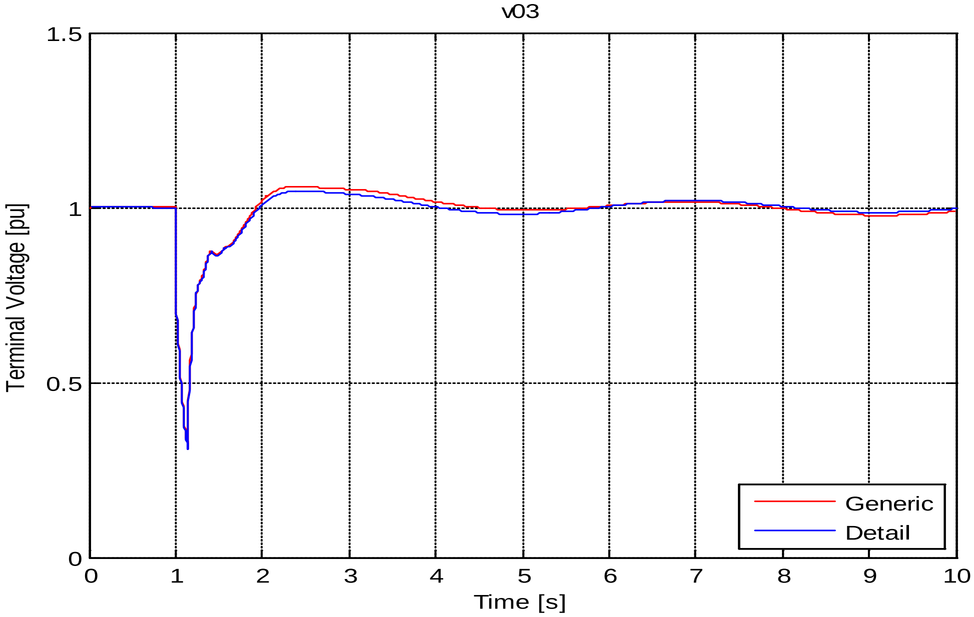

Figure A9 Terminal voltage of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.3 per unit

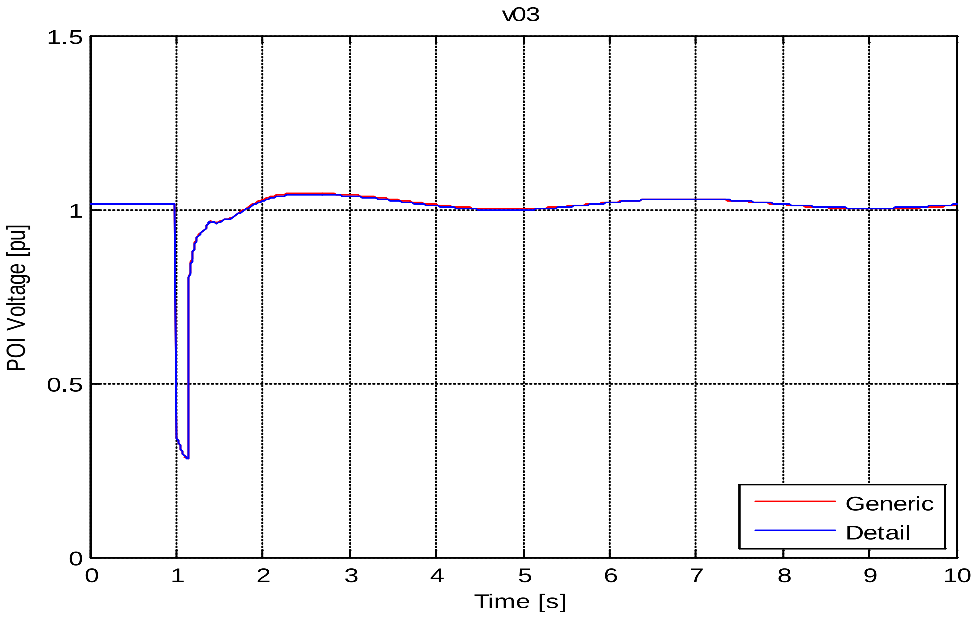

Figure A10 POI voltage of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.3 per unit

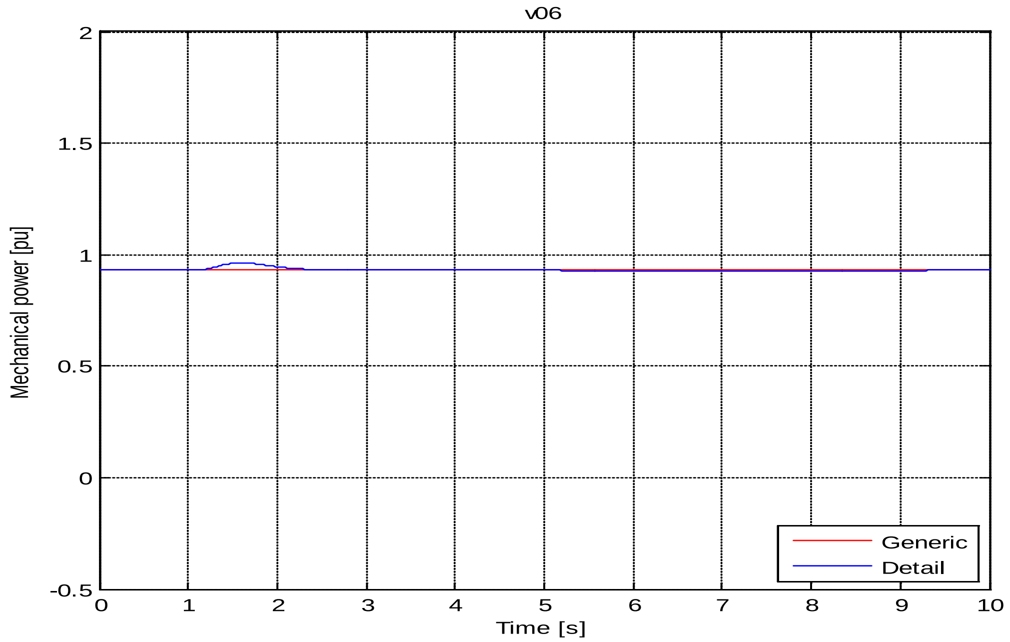

Figure A11 Mechanical power output of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.6 per unit

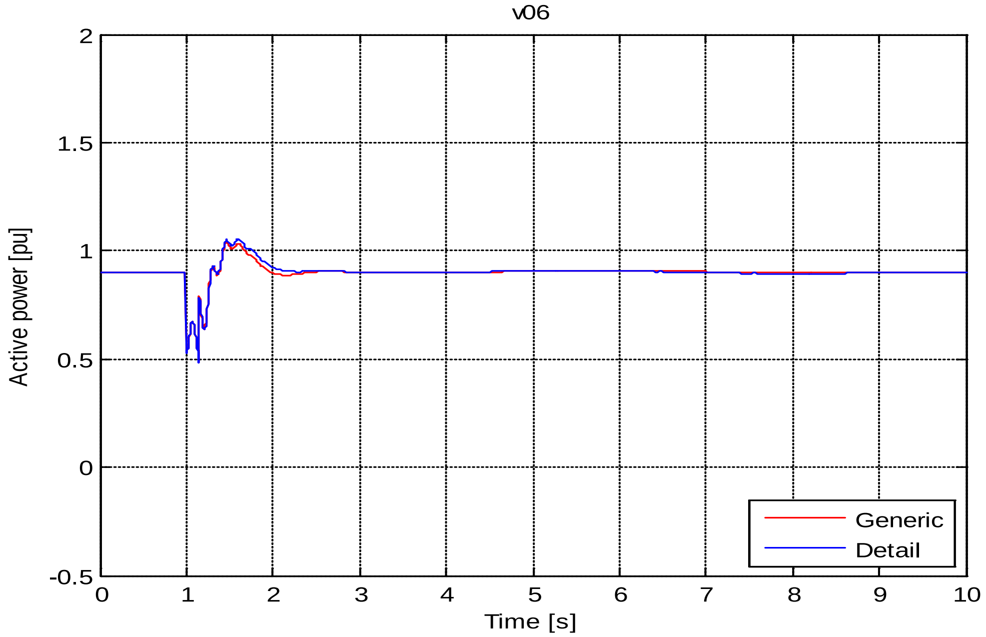

Figure A12 Active power output of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.6 per unit

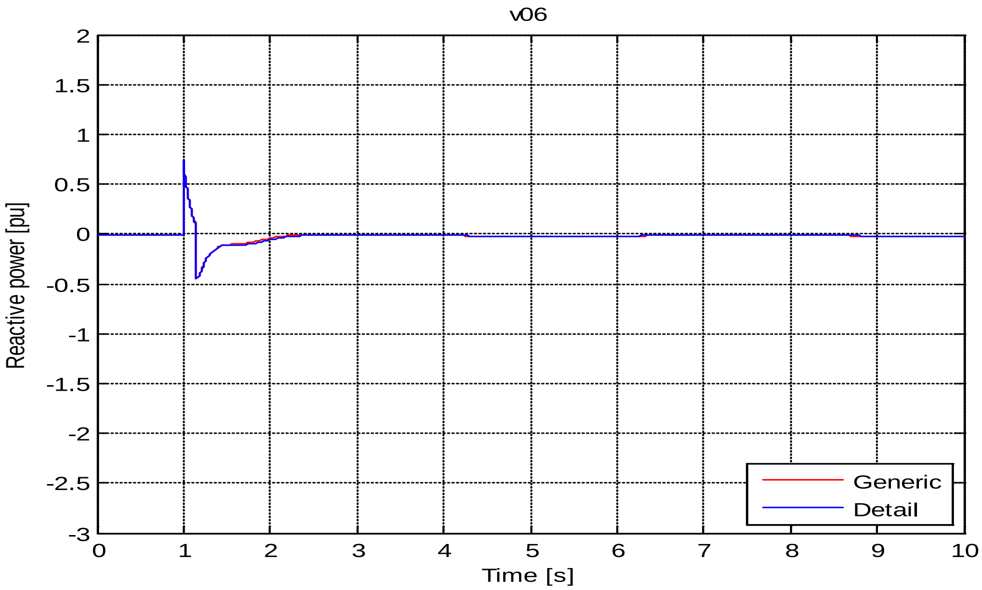

Figure A13 Reactive power output of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.6 per unit

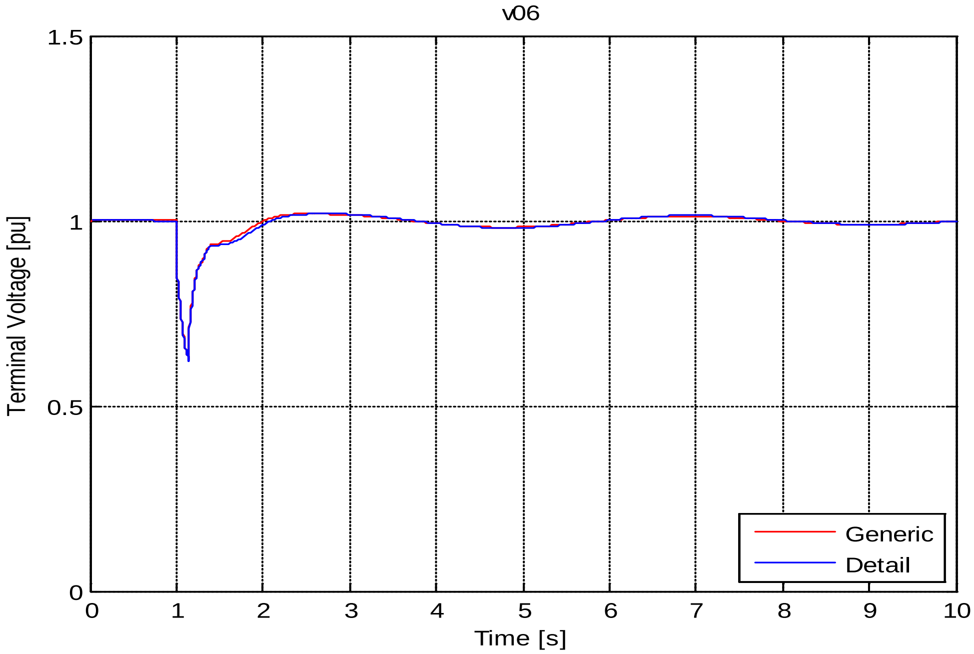

Figure A14 Terminal voltage of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.6 per unit

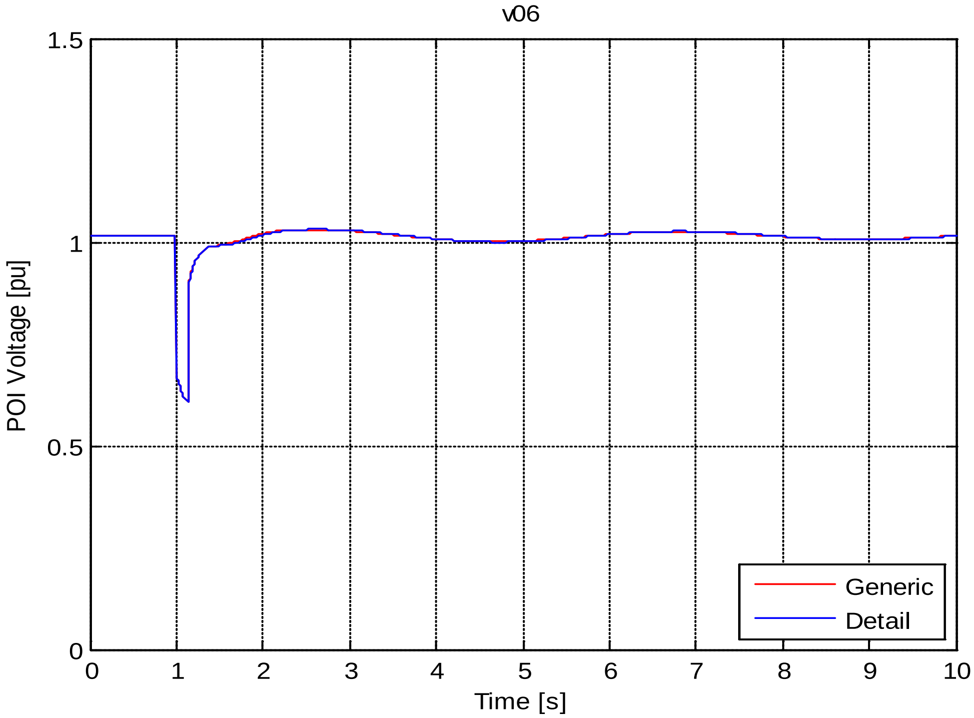

Figure A15 POI voltage of MWT1000A detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.6 per unit

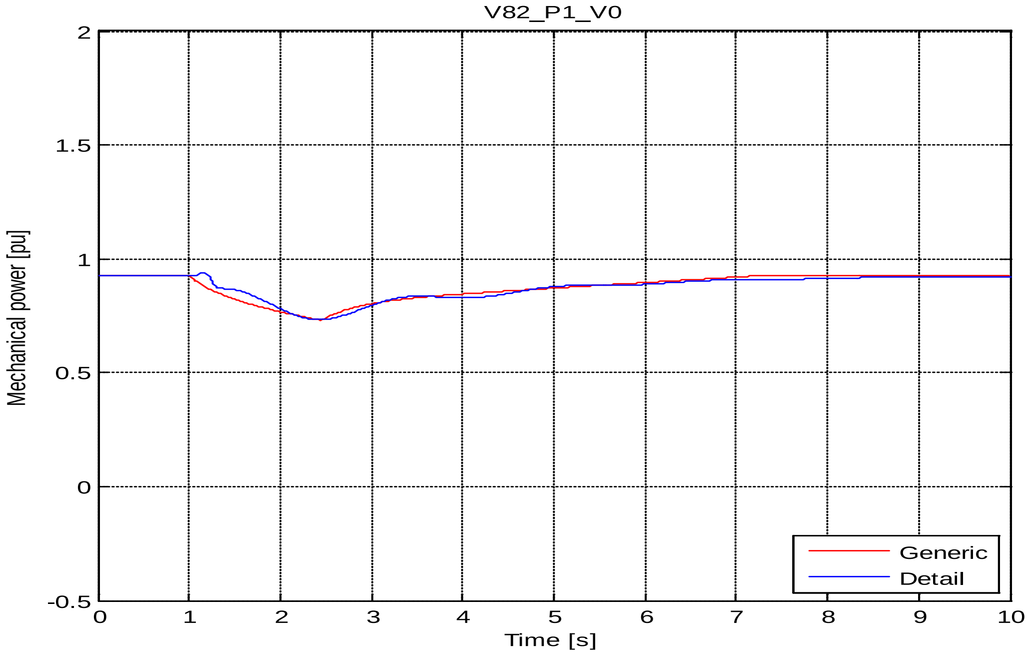

Figure A16 Mechanical power output of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0 per unit

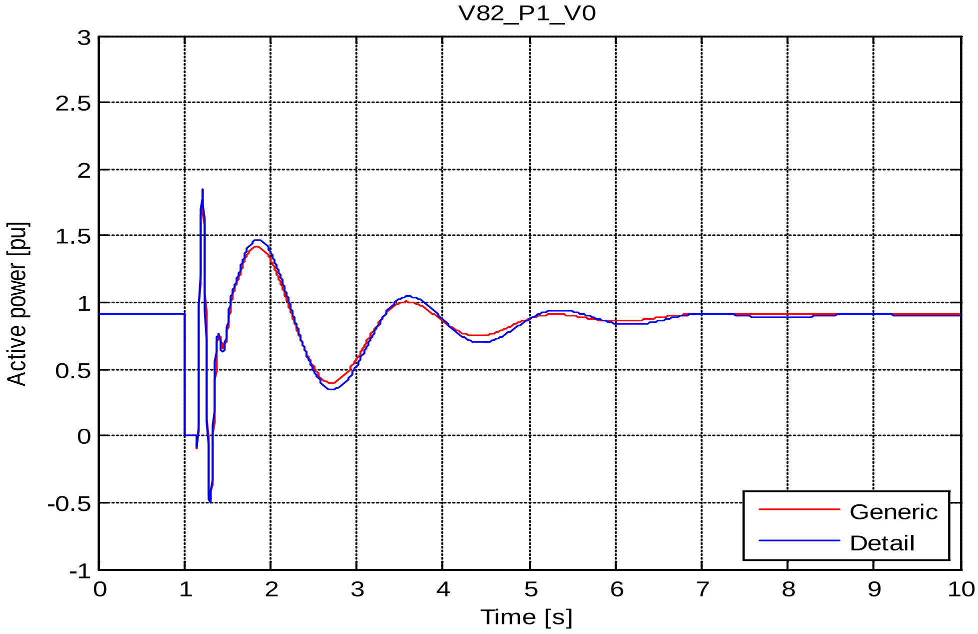

Figure A17 Active power output of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0 per unit

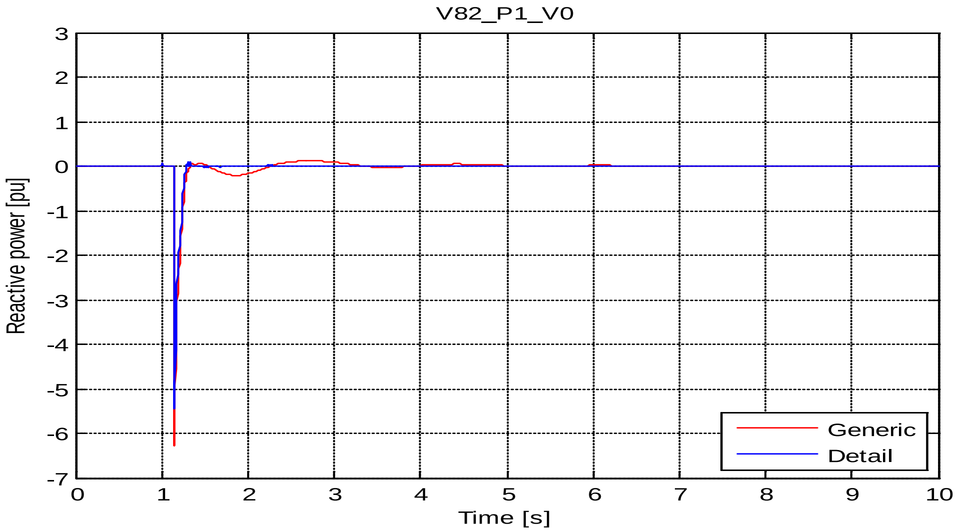

Figure A18 Reactive power output of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0 per unit

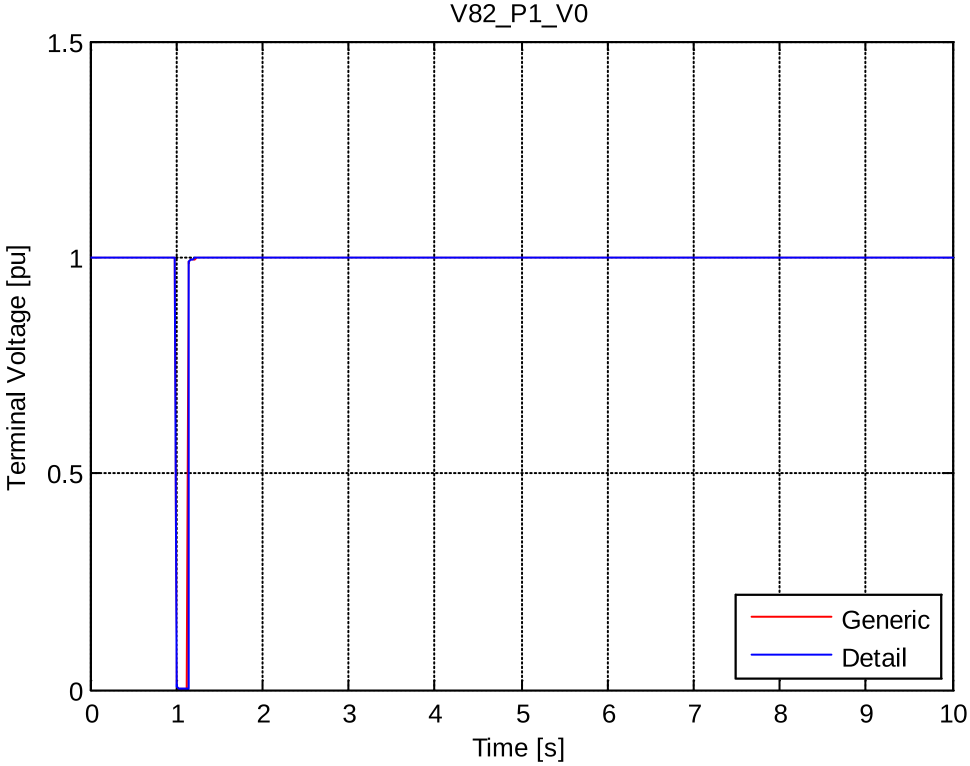

Figure A19 Terminal voltage of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0 per unit

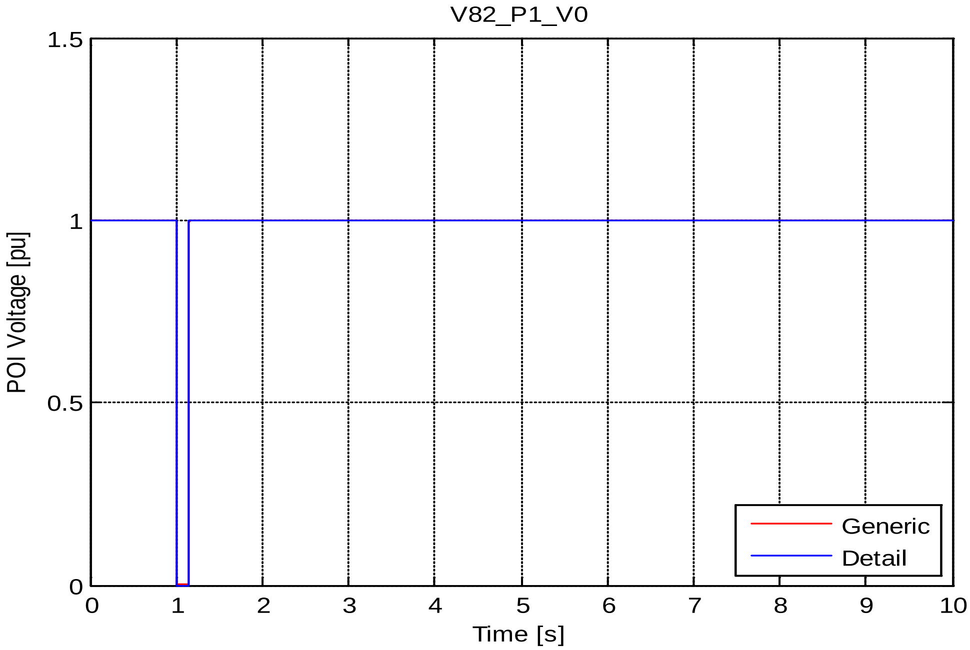

Figure A20 POI voltage of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0 per unit

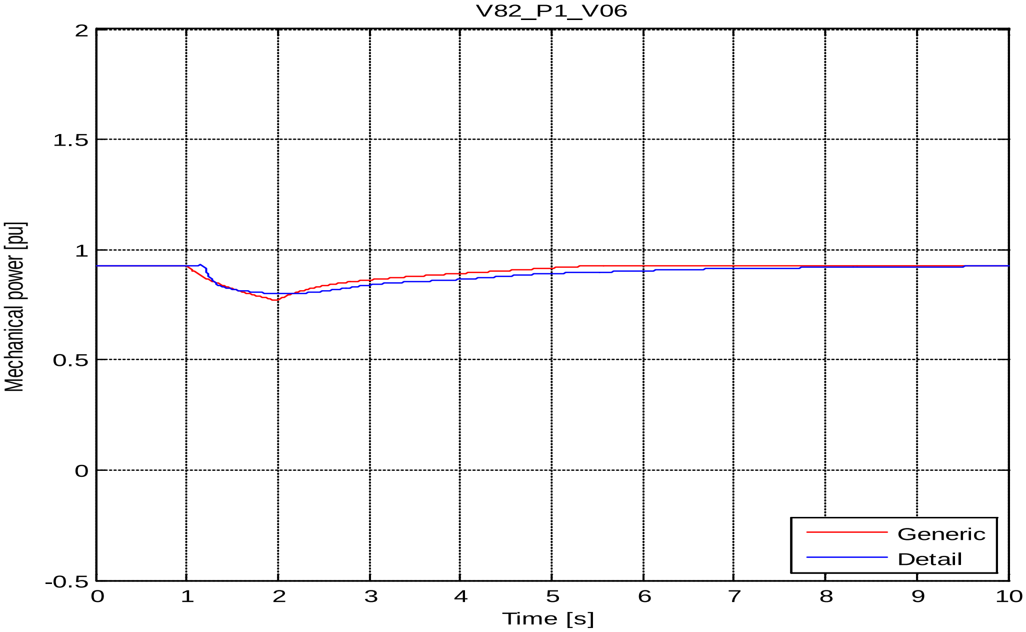

Figure A21 Mechanical power output of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.6 per unit

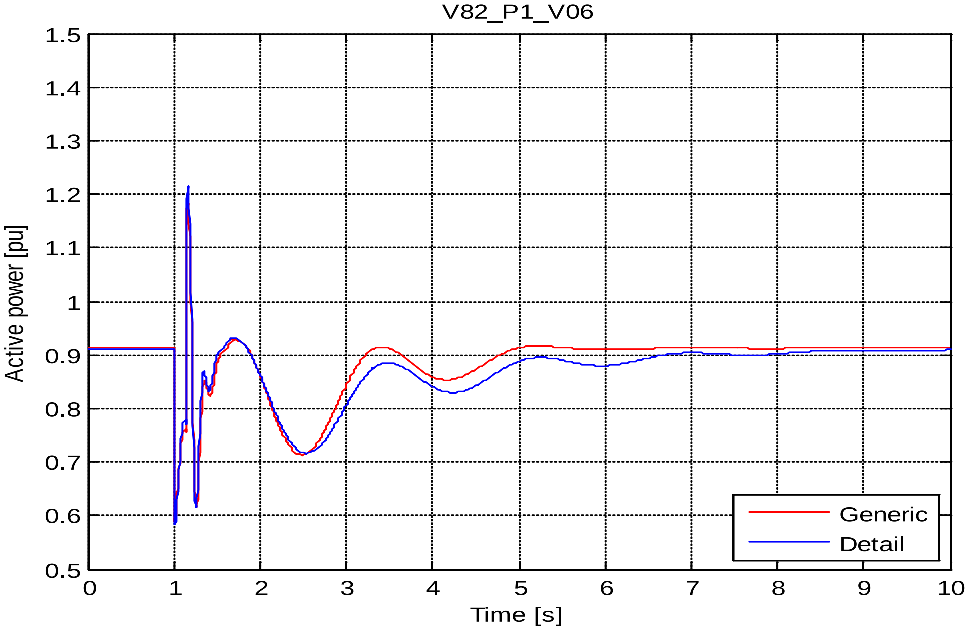

Figure A22 Active power output of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.6 per unit

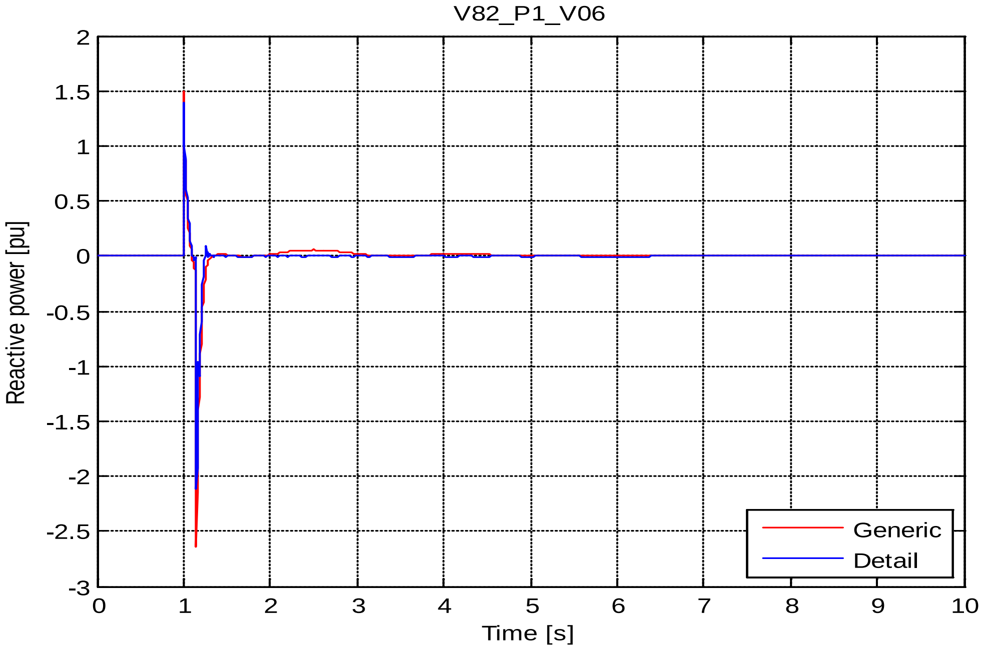

Figure A23 Reactive power output of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.6 per unit

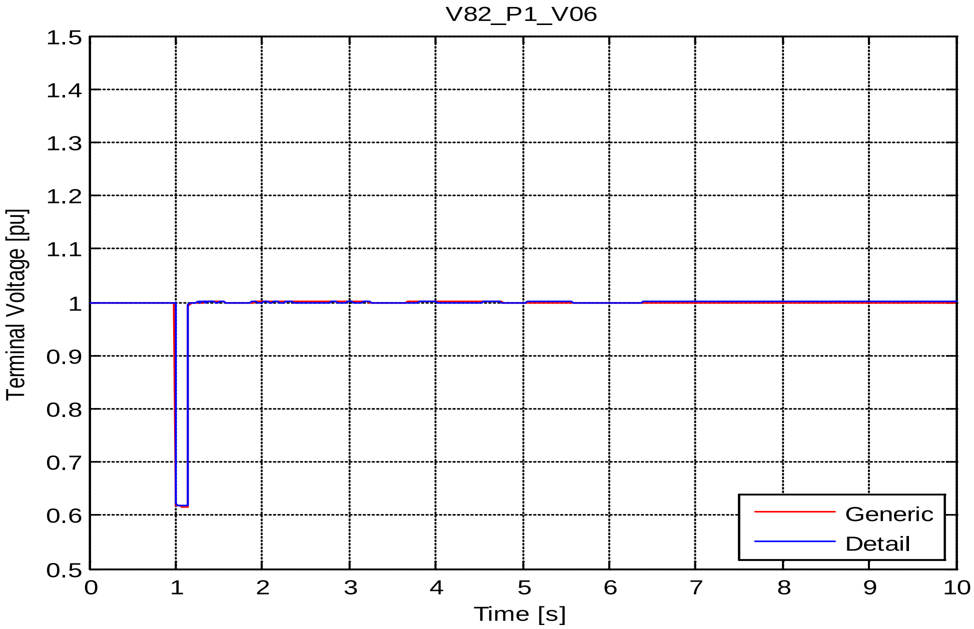

Figure A24 Terminal voltage of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.6 per unit

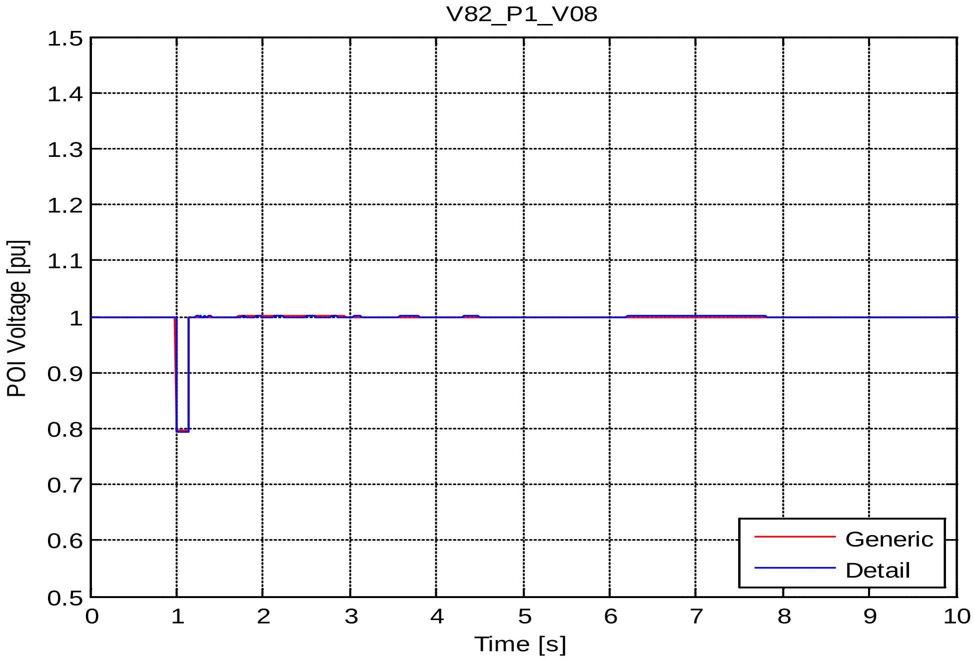

Figure A25 POI voltage of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.6 per unit

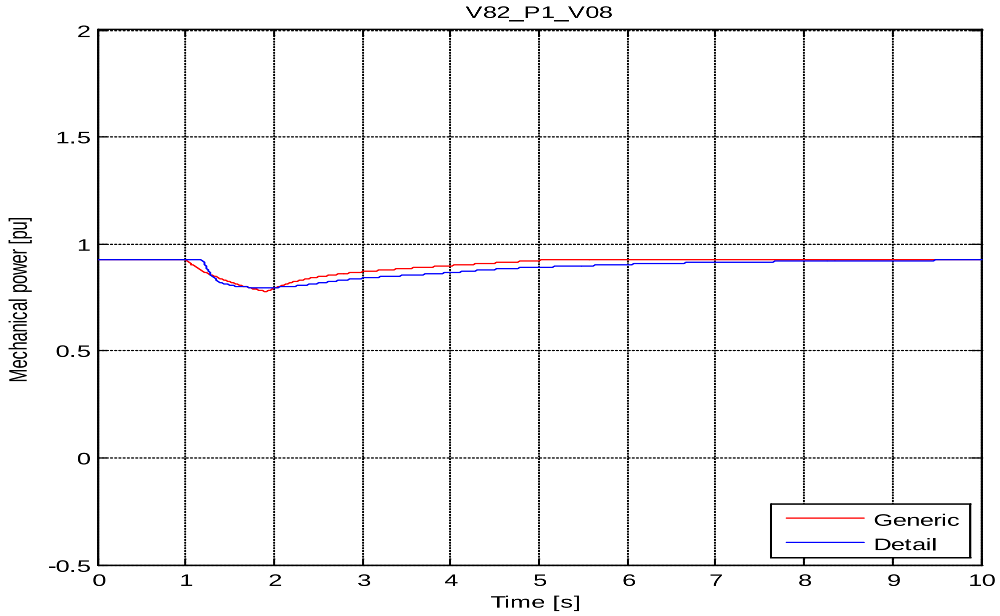

Figure A26 Mechanical power output of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.8 per unit

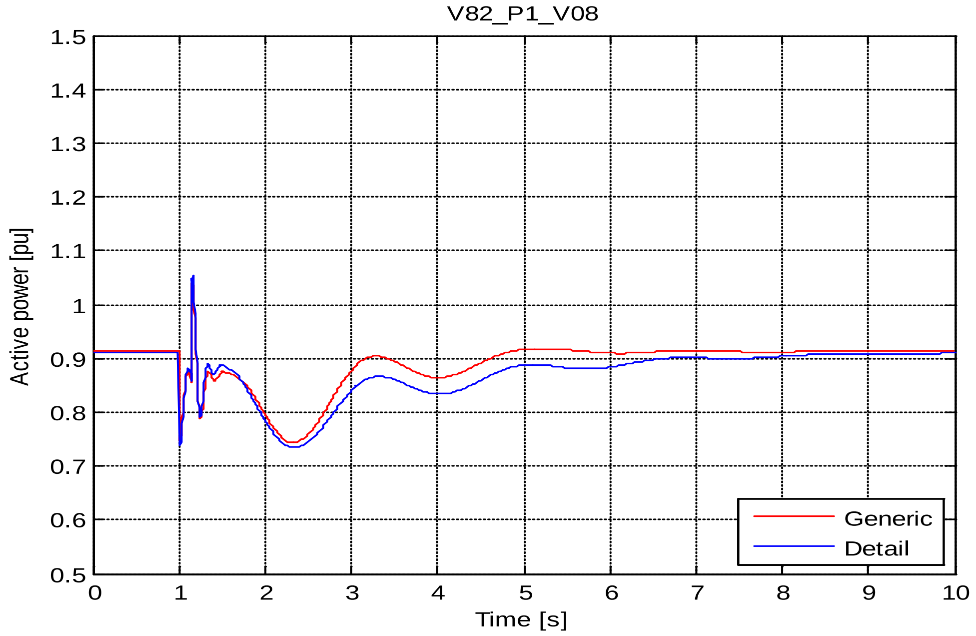

Figure A27 Active power output of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.8 per unit

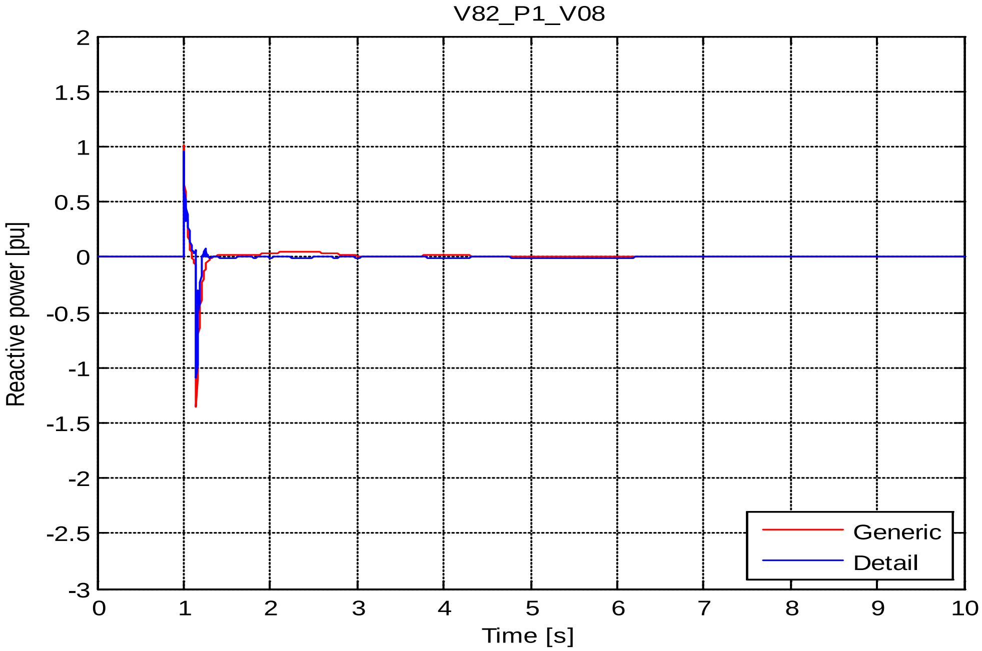

Figure A28 Reactive power output of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.8 per unit

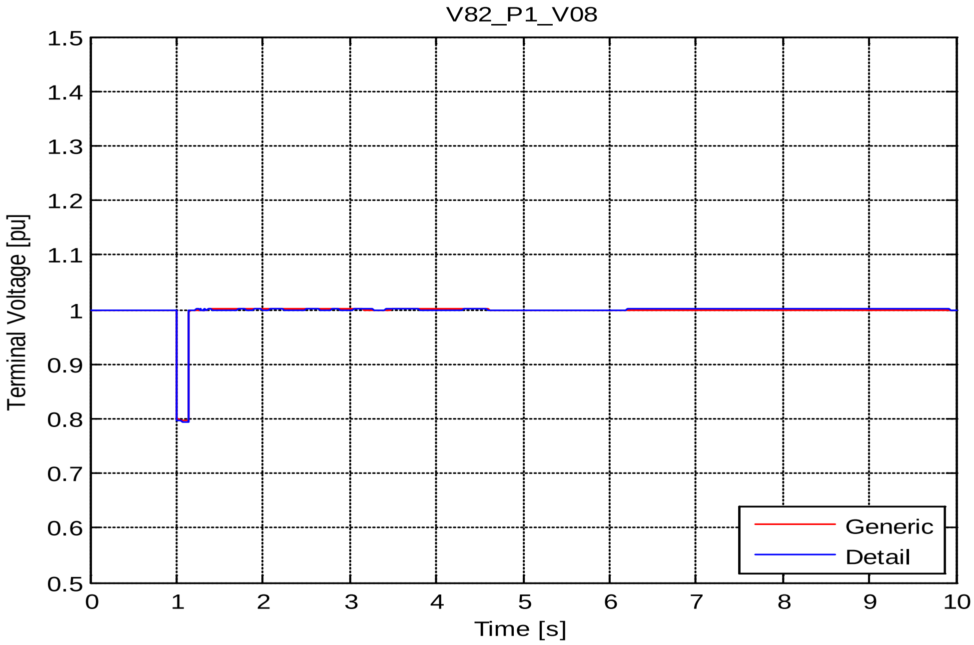

Figure A29 Terminal voltage of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.8 per unit

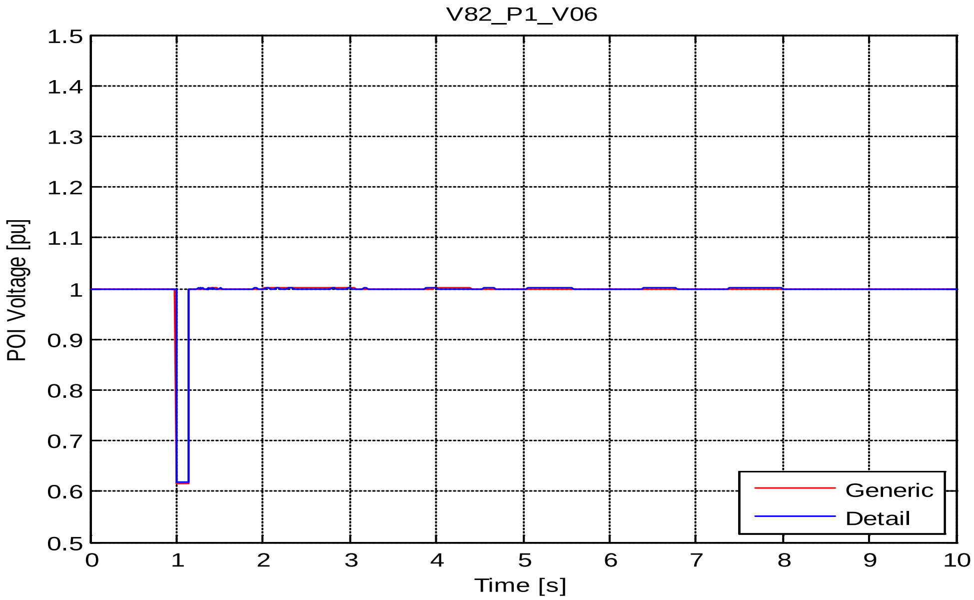

Figure A30 POI voltage of V82 detailed model (blue line) versus pseudo governor model (red line) when voltage drops to 0.8 per unit