# A New Thermal Governor Modeling Approach in the WECC

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***Abstract*—Recordings of large generation trips in the Western Electricity Coordinating Council (WECC)[1] indicate that only about 40% of the simulated governor response actually occurs. This paper presents the development of a new turbine-governor modeling approach that correctly represents thermal[2] units that have demonstrated unresponsive characteristics as "base loaded" units, or as units with load-controllers. The developmental work included the creation of a WECC-wide system database based on disturbance monitoring and SCADA recordings of staged tests. The new modeling approach has been extensively validated against recordings from three WECC system tests and several large disturbances and has been recommended for use in all operation and planning studies in the WECC. Current effort is to obtain validated data for the new models from generator owners that will replace the developmental database. The new modeling results in improved dynamic simulations of thermal and hydro plant responses, of power flows in key interties, and of system oscillations following large generation trips.**

***Index Terms*—Governors, interconnected power systems, power system dynamic modeling, power system dynamic performance, power system simulation.**

## I. Introduction

Numerous trips of large generating units and plants rated up to 2000 MW in the Western Electricity Coordinating Council (WECC) over the years have indicated a wide discrepancy between simulations of frequency and corresponding recordings from disturbance monitoring equipment. The differences in frequency have been noted in both the initial transient dips and in the "settling" frequencies. Assessment of the first transient dip is important for load shedding while the settling frequency is a measure of the responsiveness of turbine-governors in the system.

In early 2001, the WECC proposed new criteria to meet the new NERC policies for Frequency Responsive Reserves (FRR). The new proposed policy, NERC Policy 1C, specifies the minimum MW component of FRR that should be achievable in 60 s. Accurate simulations of governor responses to system frequency deviations during generator trips are central to implementing the new requirements; thus accurate turbine-governor modeling, always high on the WECC modeling list [1], has become a critical issue.

To further the governor modeling investigation, two generation trip tests were performed on May 18, 2001 to determine the response of governors throughout the system with all automatic generation controls (AGCs) switched off. In separate tests, 750 MW and 1250 MW were tripped in the Southwest and in the Northwest, respectively. The two tests indicated that only 40% of the expected governor response in the system actually occurred in the "settling"' time of 60 s or thereafter as a result of the initiating generation trip. However, existing modeling practice assumes that 100% of governors respond in accordance with the 5% speed droop governor characteristic. This results in a significant difference between simulations and actual recorded system responses. The principal reason for this large discrepancy is that base loaded and load limited generators, and units operating with load controllers, are not properly modeled. These are primarily thermal and gas turbine units. Investigations indicated that other affects such as nonlinear gate movement, dead band etc have an impact on simulation results, but a relatively minor one in comparison. In the modeling of governors, the base-load and load controller operation of units is clearly the dominant effect.

This paper describes the developmental work leading to the selection and validation of the new thermal governor modeling approach in WECC. The work commenced with the WECC generation trip tests on May 18, 2001, followed by the application of a new thermal governor-load controller model (the GE "ggov1" model), and the creation of a WECC-wide system database based on disturbance monitoring and SCADA recordings of the tests and other disturbances.

The turbine-governor modeling effort followed a three-step process of Development, Validation and Verification. "Development" of the modeling was based on the recorded responses of the system and individual generating units during the 1250-MW Northwest Trip Test of May 18, 2000. "Validation" of the model was performed by simulations and comparison to recorded responses of the May 18, 2001 Hoover 750-MW trip test and the June 7, 2000, Grand Coulee 750-MW system trip test. All three staged tests were performed with AGCs switched off. "Verification" of the model was performed by comparing simulations

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[1]WECC were formerly the Western Systems Coordinating Council (WSCC).

[2]Thermal plants embrace conventional fired steam, nuclear system, simple cycle gas turbine, and combined cycle gas turbine plants.

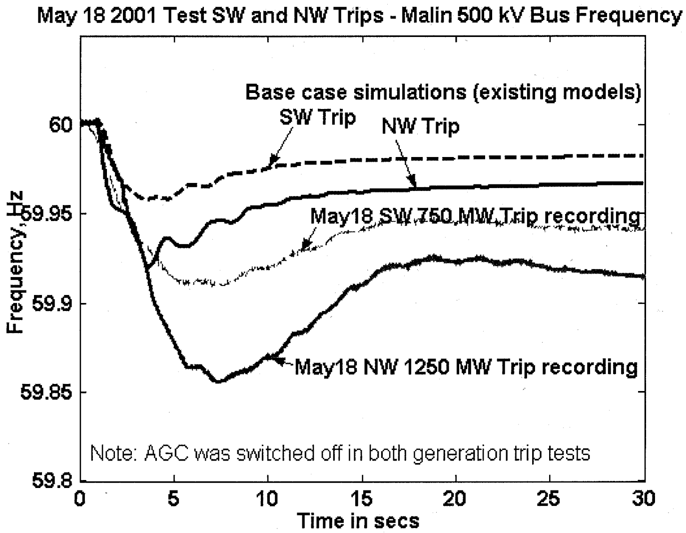


Fig. 1. Frequency recordings of the SW and NW trips on May 18, 2001. Also shown are simulations with existing modeling (base case).

with recordings of several recent generation trips in the WECC ranging from 950 to 2800 MW.

Validation of the new modeling approach based on simulation of base loaded units and load controller units led to the recommendation and approval of the new thermal governor modeling for the WECC. The ongoing effort is to obtain validated data for the new models from generator owners.

## II. WECC Frequency Response Tests of Turbine-Governors on May 18, 2001

Two generation trip tests were performed on May 18, 2001 in the WECC to determine the frequency response operation of governors. In these tests, 750 MW was tripped at Hoover hydro power plant in the Southwest; and in a second test, 20 min later after frequency had stabilized, a total of 1250 MW was tripped in three hydroplants in the Northwest at Grand Coulee, Chief Joseph, and GM Shrum. AGC was switched off during the tests so that the pickup of generation in the system after the trip was due entirely to governor action. Disturbance monitoring and SCADA recordings were taken throughout the system. The tests were performed under light load (spring) conditions. Previously performed system studies ensured that there should be no risk to the system in these operating conditions from these tests.

Fig. 1 shows the frequency recordings of the SW and NW trips on May 18, 2001. Also shown are simulations with existing modeling[3] that clearly indicates the wide disparity between the simulations and the recording of the disturbance.

The simple calculation below indicates that only about 40% of the effective response of governors occurs in the real system. Note that this is a simplistic first approach to a complex response of units in the system. Load damping and the effect of redistributed losses are neglected.

Generation tripped in the May 18 NW $\text{Test} = 1250$ MW.

WECC generation capacity on-line during $\text{Test} =$ 91 000 MW.

[3]Simulations using existing modeling are also termed "base case" modeling in the other figures in this paper.

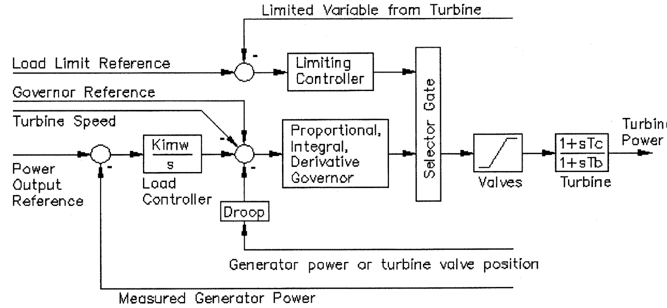


Fig. 2. Overall configuration of thermal turbine-governor, load controller, and limiting controller.

If all governors were responsive, and had a 5% droop

$r = \text{Droop (regulation)} = 0.05$ p.u.

$D = \text{Damping} = 0$

settling frequency deviation, $\text{Hz} = 0.105$

$\Delta\omega = $ Frequency Deviation, pu $= 0.105/60 =$ 0.001 75 p.u.

$\Delta P = \text{Generation\_Pickup}, 91000$ MW base $=$ 3185 MW

*calculated_from*

$$\frac{\Delta\omega}{\Delta P} = -\left(\frac{1}{\frac{1}{r} + D}\right)$$

The theoretical pickup is 3185 MW, but the actual pickup was only 1250 MW. Hence, the percentage of responsive governors with a 5% droop = (1250/3185) = 39%.

## III. Development, Validation and Verification of the New Thermal Governor Modeling

### A. Modeling Approach

The new turbine governor modeling approach was adopted to enable the effective representation of units that have been seen to be unresponsive to frequency changes. This modeling recognizes the diverse reasons for such behavior and handles units whose output is managed by load controllers, units running at fixed valve opening, and units running at load limits such as the temperature limits of gas turbines. The principal elements of typical thermal plant governor and controls are shown in Fig. 2 and further details of its implementation are shown in the Appendix. The parameters of importance in this work are detailed in Table I. Many other modeling parameters were assigned typical values as appropriate to represent the internal behavior of steam and gas turbine plants.

The governor is a proportional-integral-derivative (PID) type with a permanent droop feedback r, typically 5%. The load (power) controller is a simple reset controller. The reset feature of the controller regulates the speed/load reference of the governor. The key parameter is the gain *Kimw*; typical values for steam units are 0.01 for "fast" control and 0.001 to 0.005 for "slow" control. "Base" load operation is simulated by setting the limiters to limit the turbine power to a preset value. It is essential that the load controller reference[4] and load limit

[4]This is designated "power output reference" in Fig. 2 and "Pmwset" in Fig. 21..

reference reflect the actual dispatched power of each generator as obtained from the initial condition load flow. Accordingly, these references, and valve position limits where appropriate, must be set in the initialization of each individual dynamic simulation run.

The turbine is represented by a simple linear lead-lag transfer function model. The principal parameters of the model used in the studies described in this paper are given in Table I.

### *B. Three-Step Process for Modeling*

Application of the new thermal turbine-governor modeling to about 1100 thermal units in the WECC system followed a three-step process of development, validation, and verification.

- "Development" of the WECC database model parameters for the new thermal governor model was based upon the recorded responses of individual generating units and the system from the 1250-MW Northwest Trip Test of May 18, 2001.
- "Validation" of the model was based on the recorded responses of the Hoover 750-MW trip test on May 18, 2001. Further validation was based on recorded responses to the Grand Coulee 750-MW trip test on June 7, 2000.
- "Verification" of the model was performed by comparing simulations with recordings of several other system disturbances including the Colstrip 2000-MW trip on August 1, 2001, Diablo 950-MW trip on June 3, 2002, PDCI bipole trip and 2800-MW RAS in the Northwest on June 6, 2002, and other disturbances.

"Validation" involved staged generation trip tests (with AGC off) for which data and recordings were collected from the control areas and basecases were created to specifically model system conditions during the tests. For "verification," basecases representing typical system conditions were used in the simulations. For all major events, system recordings of frequency, voltages, and flows at critical 500-kV buses and interties were obtained from disturbance monitoring equipment permanently installed in various critical locations of the WECC system.

### *C. Selection of Thermal Turbine-Governor Data in the Development Stage*

For the selection of the thermal governor data in the developmental phase of the model, disturbance monitor recordings and over 200 SCADA response recordings of generator electrical power were evaluated from the May 18, 2001 system test. In this evaluation, characteristically similar responses were noted for a large number of units. These were categorized under five "response" categories depicting responsiveness in varying degrees, and were coded T1 to T3 for steam thermal units, and G1 to G2 for gas turbine units. Each of the 1100 ggov1 governor models was given a code. Where SCADA data was not available for a specific unit, information obtained from a survey of owners/control areas regarding the base loading or responsiveness of their units was utilized in the selection of the turbine-governor code. Data for the turbine-governor model with the designated codes are presented in Table I.

TABLE I
PRINCIPAL PARAMETERS OF THE NEW THERMAL TURBINE-GOVERNOR MODEL GGOV1 FOR THE VARIOUS DESIGNATED CODES

| | | | | | P | I | D | |
|---|---|---|---|---|---|---|---|---|
| Code | | r | Tb | Tc | Kpgov | Kigov | Kdgov | Kimw |
| T1 | Fast load controller | .05 | 10 | 2 | 10 | 2 | 0 | 0.01 to 0.02 |
| T2 | Slow load controller | .05 | 10 | 2 | 10 | 2 | 0 | 0.001 to 0.005 |
| T3 | No load controller | .05 | 10 | 2 | 10 | 2 | 0 | 0 |
| G1 | With load controller | .05 | 0.5 | 0 | 10 | 2 | 0 | 0.01 to 0.02 |
| G2 | No load controller | .05 | 0.5 | 0 | 10 | 2 | 0 | 0 |

The principal parameters of the model are:

*r* Permanent Speed Droop, pu

*Tb* Turbine lag time constant, secs

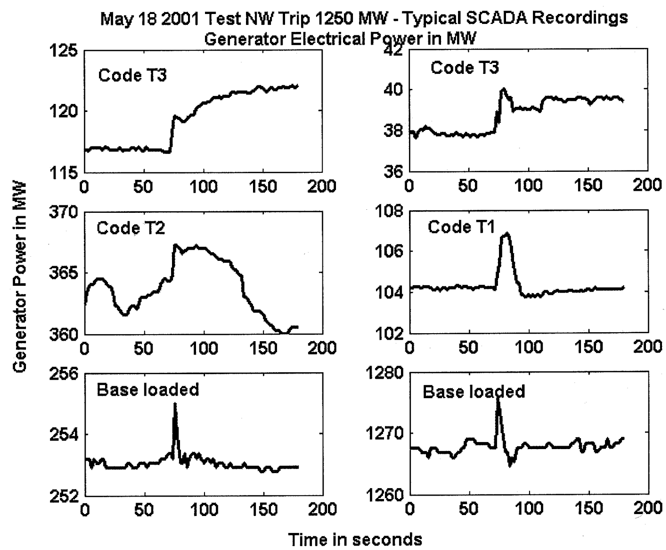


Fig. 3. SCADA recordings of the May 18 test for typical thermal units coded T1 to T3, and base loaded units. AGC was switched off during the test.

As discussed in Section V, the data in this developmental database will be replaced by validated turbine-governor data obtained from generator owners and will form the new database in WECC for all dynamic studies.

The principal parameters of the model are

- $r$ permanent speed droop, per unit;
- $Tb$ turbine lag time constant, seconds;
- $Tc$ turbine lead time constant, seconds;
- $Kp\text{gov}$ governor proportional gain, per unit;
- $Ki\text{gov}$ governors integral gain, per unit;
- $Kd\text{gov}$ governor derivative gain, per unit;
- $Ki\text{mw}$ load (power) controller gain, per unit.

Fig. 3 shows typical SCADA recordings from the May 18, 2001 Test of a typical "fast controller" unit (code T1), a "slow controller" or partially responsive unit (Code T2), "responsive" units (code T3), and base loaded units. Fig. 4 shows the SCADA responses from a random system disturbance of two units with "fast" controllers, code T1. The SCADA recordings are of generator electrical power, and therefore, include the effects of the

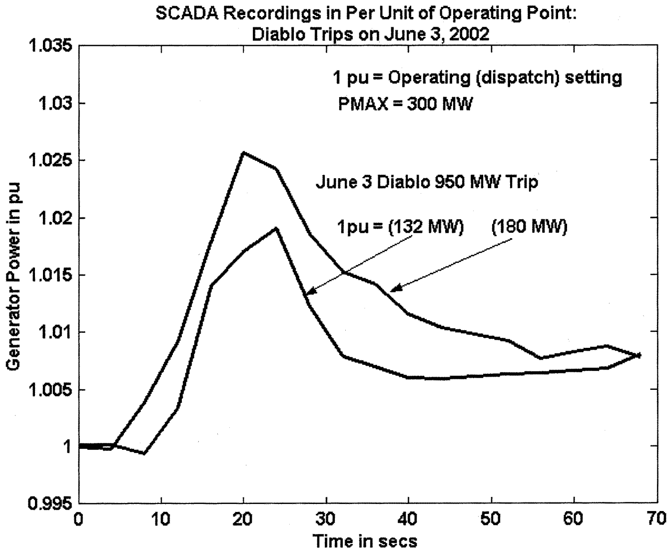


Fig. 4. Illustrating fast controller action (code T1) on two large thermal units.

system network voltages and generator excitation system responses. The characteristic initial peak typically seen at the start of the response is inertial.

### *D. Megawatt Capacity of Thermal Units With the New Model*

In the developmental database for the May 18 test, 423 "existing" thermal governor models for units totaling a maximum capacity of 82 300 MW were converted to the new governor model. [5] It was clear as the validation study progressed, that accurate simulation of the events required the introduction of governor and exciter models for the numerous units that had hitherto been represented without such models. Typical ggov1 governor models and static excitation models with assumed data were included for all such units greater than 5 MW. These totaled 36 000 MW for 425 unmodeled governors and 8670 MVA for 265 unmodeled exciters and governors. The total thermal generation on-line during the May 18th test was about 67 000 MW[6] out of a total generation of 91 000 MW.

### *E. Simulations With the New Thermal Turbine-Governor Model*

The results of the simulations for validation and verification of the new model compared with the real time event recordings are shown in Figs. 5–12. Simulations performed with existing models are also shown for comparison. The existing modeling assumes that 100% of governors respond in accordance with its 5% speed droop governor characteristic.

Fig. 5 shows simulations of two typical thermal units with load controllers of different speeds compared to the SCADA response (generator electrical power) of the units during the May 18, 2001 NW trip test. The resolution of SCADA at 4-s intervals does not pick up the detailed electrical power swings as seen in the simulations, but it does show the overall general response.

[5]Note that not all units were in operation during the May 18, 2001 test which was performed in light load conditions.

[6]Of these, about 60% was base loaded in the developmental base case.

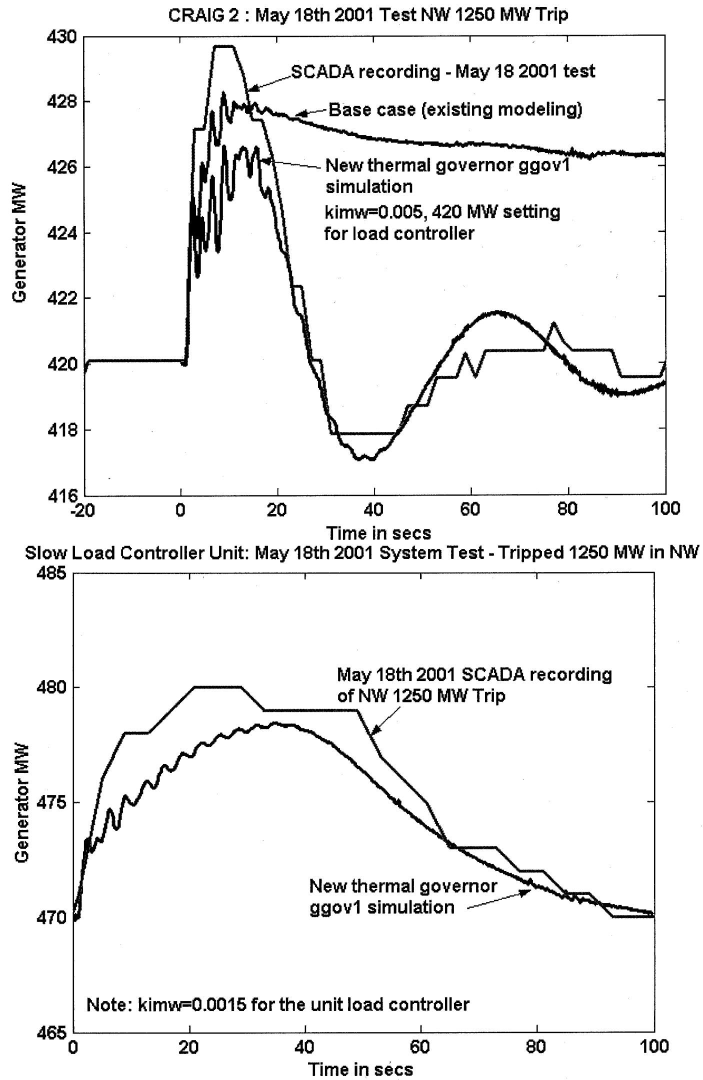


Fig. 5. (a) Simulations with the new turbine-governor model of a thermal unit with a load controller of code T2 with a faster speed compared with its May 18 test SCADA recordings. (b) Simulations with the new turbine-governor model of a thermal unit with a load controller of code T2 with a slower speed compared with its May 18 test SCADA recordings.

Fig. 6 shows the simulation of a typical base-loaded unit. Simulations of Code T3 units (no load controllers) are not shown because they are similar to existing model simulations.

Fig. 7 shows simulations of the May 18, 2001 NW trip of 1250 MW with the new thermal turbine-governor modeling compared to test recordings from disturbance monitoring equipment. The new modeling accurately captures the first transient dip and settles at a frequency close to that obtained in the May 18 test disturbance monitoring recordings. Simulations with the existing models (base case) are also shown for comparison.

"Validation" of the new modeling was performed based on the recorded responses of the May 18, 2001 Hoover 750-MW trip test and the June 7, 2000 Grand Coulee 750-MW system trip test, shown in Figs. 8 and 9, respectively.

Figs. 10–12 show simulations in the "Verification" of the new model comparing with disturbance monitoring recordings of three large system disturbances: the Colstrip 2000-MW trip on Aug.1, 2001 (Fig. 10), the PDCI bipole trip and 2800 MW SPS

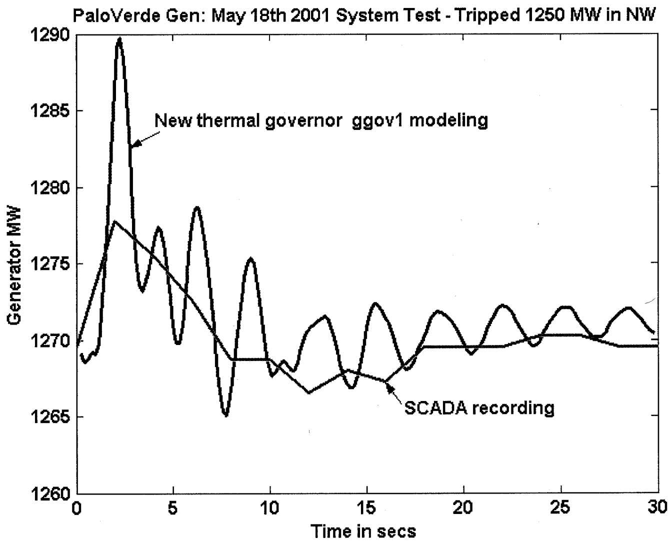


Fig. 6. Illustrating the simulation of a typical "base loaded" unit compared with its May 18 test SCADA recording.

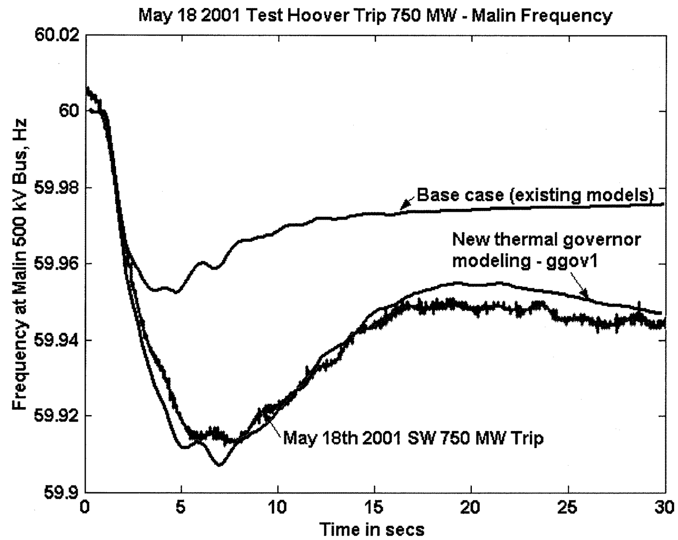


Fig. 8. Governor model validation—Hoover May 18 test simulation, 750-MW generation trip, AGC switched off.

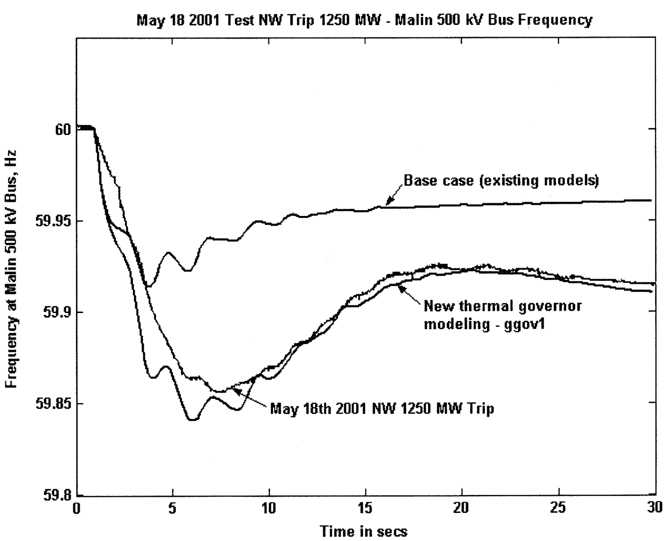


Fig. 7. Simulations with the new ggov1 governor model compared with May 18 system test recordings for the NW 1250-MW trip, AGC switched off.

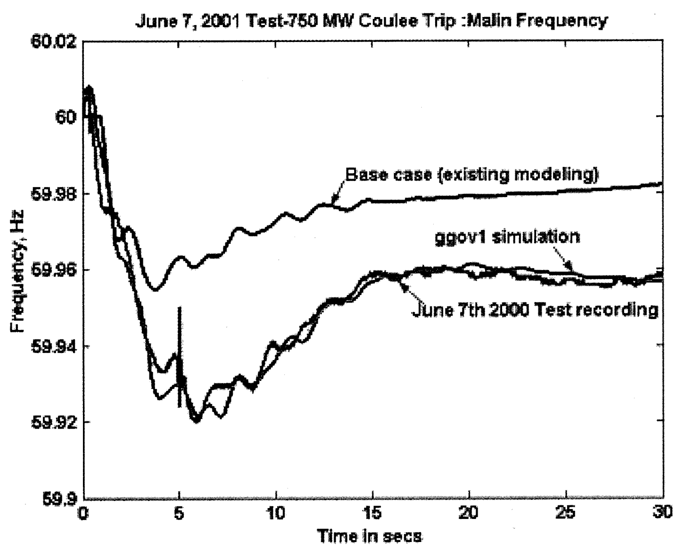


Fig. 9. Governor model validation—June 7, 2000 test simulation, 750-MW grand Coulee generation trip, AGC off.

operation in the Northwest on June 6, 2002 (Fig. 11), and the Diablo 950-MW trip on June 3, 2002 (Fig. 12). Simulations with the existing models (base case) are also shown for comparison.

The principal differences between the simulations of the "validation" tests of May 18, 2001 and June 7, 2000, and the random system disturbance recordings used in "verification," were that in the staged tests (a) the AGC was switched off to yield pure governor responses of units; (b) simultaneous SCADA data were obtained from all control areas; and (c) generator dispatch and power system data were gathered from control areas to create the databases and simulate the staged events more accurately. For the random system events simulated, the closest available basecase was used for simulation. System recordings of frequency, voltages and flows at critical 500-kV buses and interties were obtained from disturbance monitoring equipment installed in various critical locations of the WECC system for all events.

### *F. Sensitivity of Parameters*

A number of sensitivity studies were performed to determine the effect of varying parameters in the dynamic database. Clearly, the greatest effect was the selection of the base loaded, or nonresponsive generators, and the choice of "fast" or "slow" load controllers. The method of governor code selection was described earlier in this paper. Fig. 13 shows the effect of varying the selection of the base loaded and load-controlled generators.

Sensitivity studies showing the effect of fast and slow load controllers on the system are demonstrated by a "macro" study varying the speed of all load controllers in the system, see Fig. 14. Kimw is the gain of the load controller—see Fig. 2 and Table I for details.

The effect of varying Kimw on the response of a specific unit is illustrated in Fig. 15, varying from a quick-acting controller

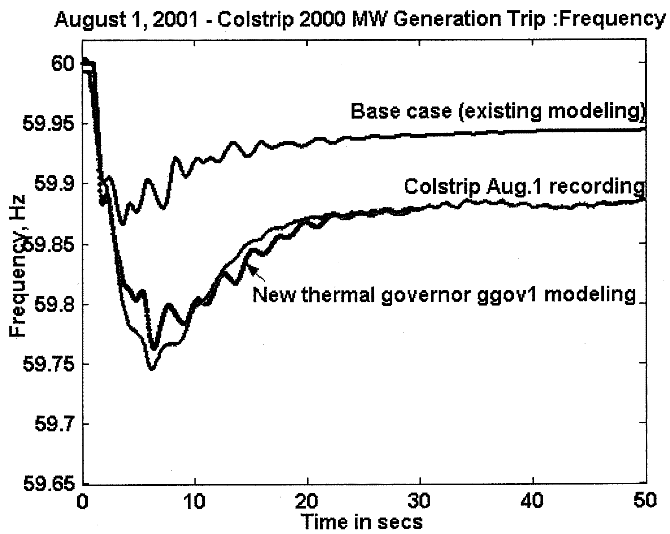


Fig. 10. Governor model verification, 2000-MW Colstrip trip on August 1, 2001.

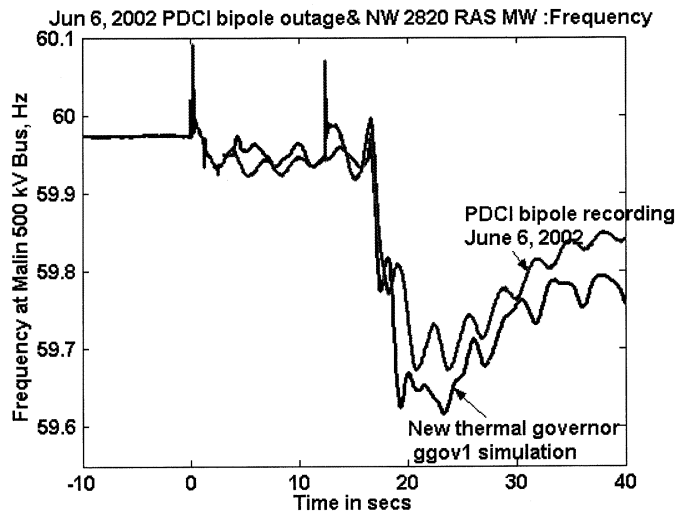


Fig. 11. Governor model verification—pacific dc bipole trip and 2800-MW NW generation trip on June 6, 2002.

($\mathrm{Kimw} = 0.01$) to a very slow controller ($\mathrm{Kimw} = 0.001$). The final selection for the developmental database was evaluated from SCADA responses.

Other sensitivities studied included varying the proportional and integral gains of the PID governors (the derivative gain was maintained at zero) and varying the Tb, Tc parameters of the turbine model. These studies resulted in varying levels of impacts, but generally less than the effect of base loading, or varying the load controller gain, Kimw, of the thermal units.

## G. Effects of AGC

For studies extending to long periods, such as for system oscillations and dynamic voltage stability, it is desirable to model AGC. Comparison of the system recordings of the May 18 test when all AGCs were switched off, and the system recording of the Colstrip 2000-MW trip on August 1, 2000, clearly indicates that AGC does make a difference in the frequency response of the system. This is illustrated in Fig. 16.

In the simulations illustrated in Figs. 10–12 of random system disturbances, certain units that would otherwise have been designated as unresponsive were modeled as responsive units in order to achieve an AGC-like effect. Proper AGC modeling is an ongoing task. With the new governor modeling approach that represents unresponsive units more accurately, the effects of AGC, particularly in the area of the disturbance, should be appropriately represented for more accurate simulations.

## H. Study of Dead Band and Nonlinearities

To assess the relative importance of governor deadbands and nonlinearities, sensitivity studies were run varying these parameters. These runs did not show a significant impact on the overall generation pickup of units until the deadband was increased significantly higher than ASME standard limits. Nonlinear valve movement of thermal units[7] was also analyzed.

[7]A study of nonlinear effects of hydro turbines indicated noticeable impacts on megawatt pickup.

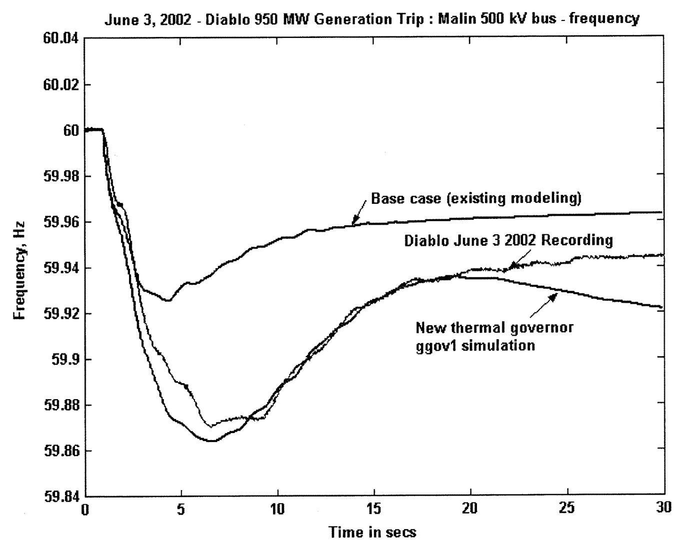


Fig. 12. Governor model verification—950-MW Diablo generation trip on June 3, 2002.

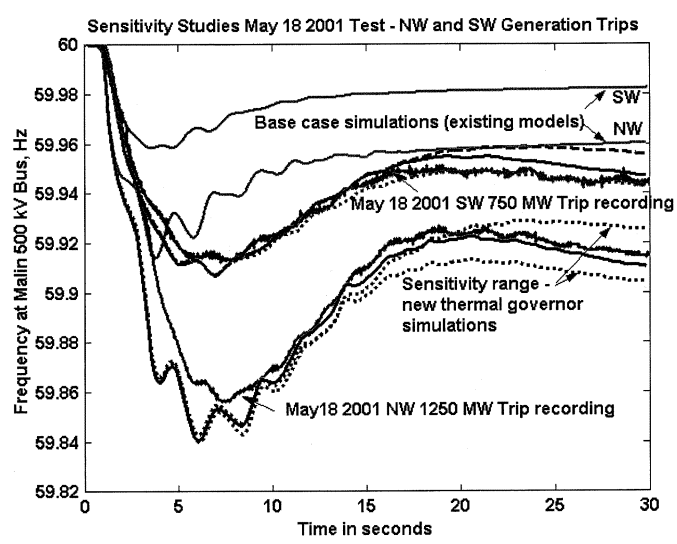


Fig. 13. Effect on system response of varying base loaded and load controlled unit selections.

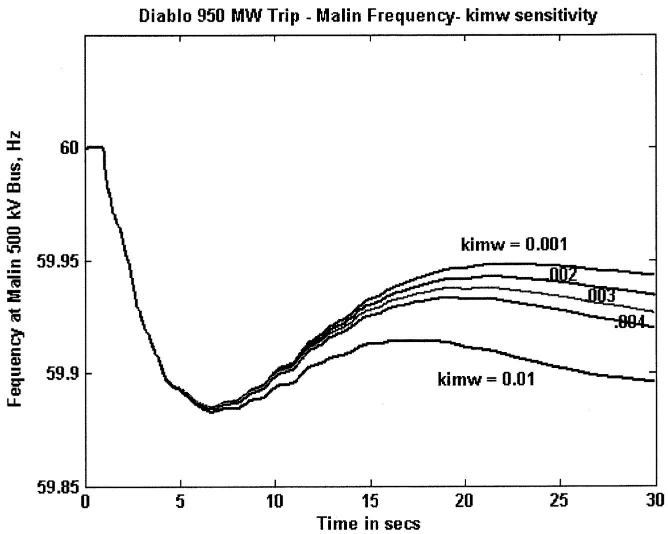


Fig. 14. Effect on system response of varying the load controller gain *Kimw* on a “macro” basis.

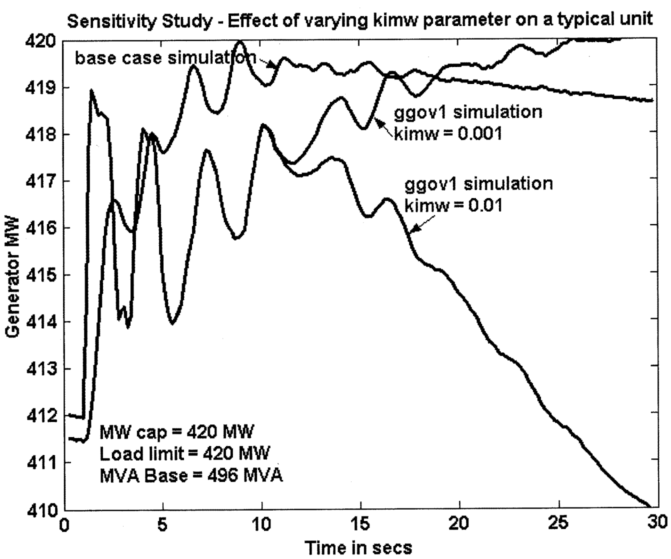


Fig. 15. Effect on generator response of varying the load controller gain *Kimw* on a single unit.

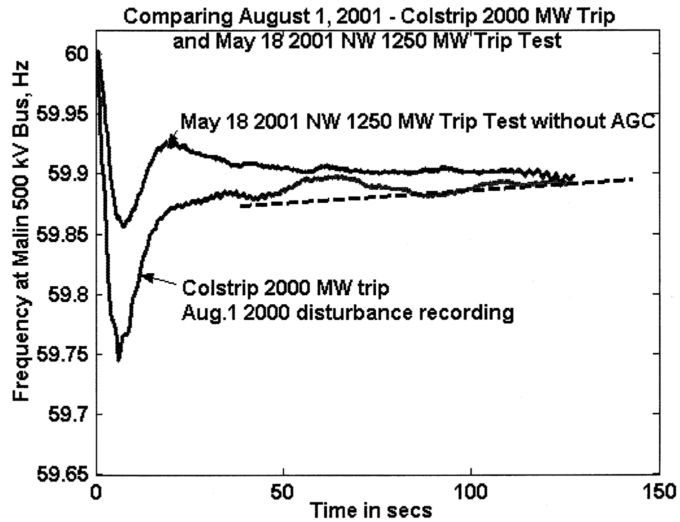


Fig. 16. Disturbance monitoring recordings comparing two real time recordings—with and without AGC.

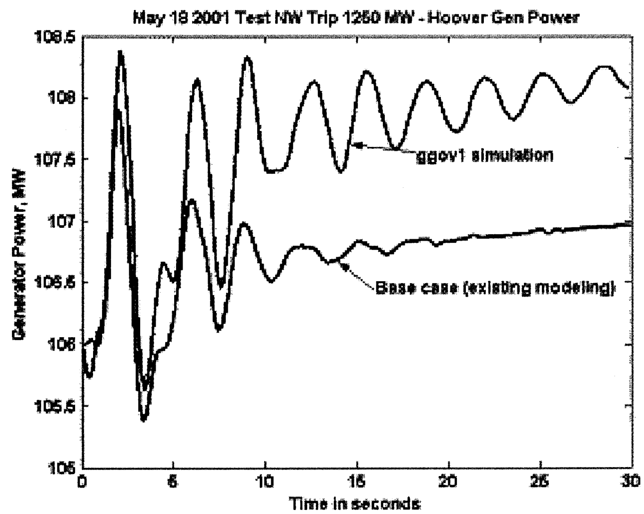


Fig. 17. Improving the accuracy of thermal plant modeling increases the generator pickup of hydro plants.

The predominant effect was, however, clearly the base loading or load-controller operation of the thermal units.

## IV. System Impacts: Thermal Versus Hydro Responses, Intertie Flows, Etc.

In the course of the validation studies, several significant impacts on the results were observed to arise from the more accurate simulations made with the new thermal governor modeling compared to simulations made with the existing modeling.

### A. Effect on Hydro Plant Responses

The improved modeling of thermal plant response results in reduced overall contribution of thermal plants to the correction of frequency and a corresponding increase in the contribution from hydro plants. Because the system frequency deviations in the simulations are greater, the output of frequency responsive hydro units correspondingly increases. Fig. 17 shows the greater pickup of a typical hydro generator during the May 18 test. Thermal plants in the WECC are predominantly in the South, and most of the hydro generation is in the North. Hence the redistribution of plant response has a significant effect in the simulation of power flows across the system, particularly in intertie flows between the North and the South, and on system oscillations [2]. Hydro governors thus clearly play a very important part in the overall response of the system for large disturbances. As a result of the improved thermal governor modeling, the accurate modeling of hydro governors in simulations assumes a greater importance. Two areas of improvement indicated by preliminary studies of hydro units are in modeling Kaplan turbine units [5] and in modeling nonlinear turbine effects.

### B. Effect on Intertie Flows

The effects on intertie flows (and oscillations) resulting from the new thermal governor modeling are shown in Figs. 18 and 19. Fig. 18 shows the simulated flows in the 500-kV Malin-Round Mountain line in comparison with the May 18, 2001 test

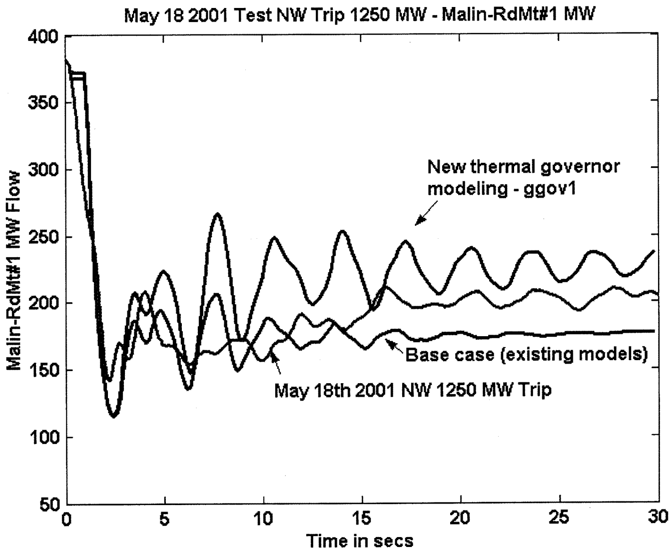


Fig. 18. Simulations of intertie flows and interarea oscillations with the new governor modeling and existing modeling for the May 18, 2001 NW system test.

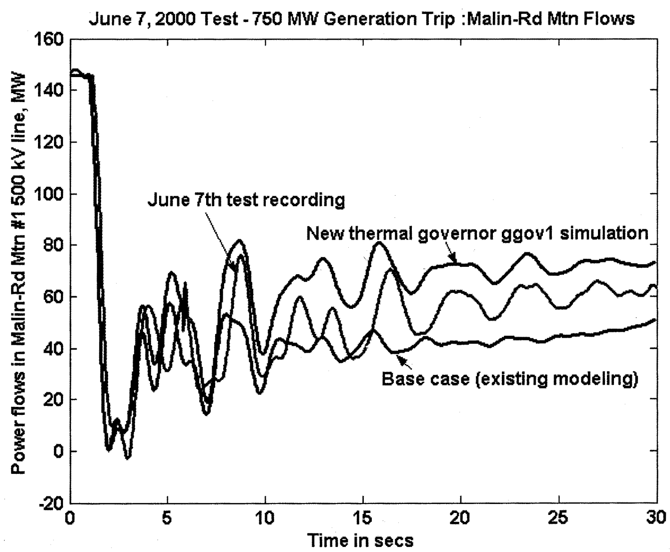


Fig. 19. Showing the difference in intertie flows and oscillations between the new governor modeling and existing (base case) modeling in simulations of the June 7, 2000 system test.

recordings for the 1250-MW trip in the Northwest and simulations with existing modeling. Fig. 19 shows the simulations for the June 7, 2000 system test when 750 MW was tripped at Grand Coulee in the NW[8] (Both these tests were performed with AGC switched off.) This line is one of the three 500-kV lines of the California-Oregon Intertie (COI) between the Northwest and the South and is a critical path in the WECC. Hence, the megawatt difference for the three-line COI path is approximately three times the megawatt difference of the one line. Note that this critical path was loaded at only 25% of its full rating during the May 18 test.

[8]There was a 10-MW difference in the line flows between the actual event recording and the power flow case. This was offset in the plot to facilitate comparison.

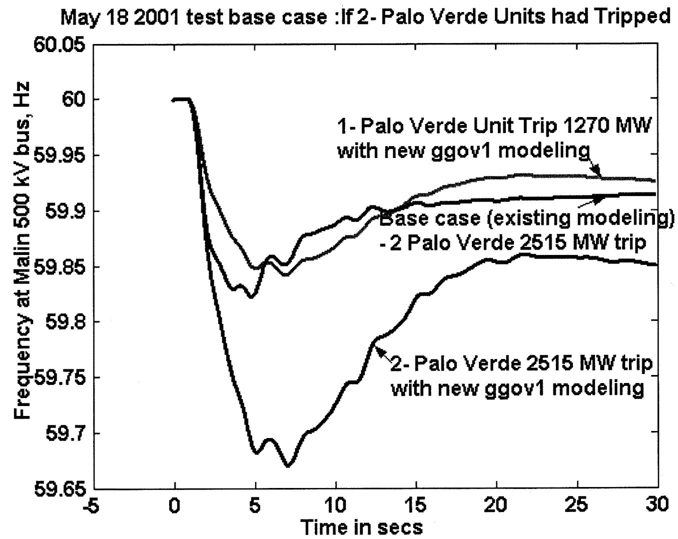


Fig. 20. Prediction of system frequency for a two-Palo Verde generation trip (2700 MW) in the WECC—comparing existing and the new thermal governor modeling.

### C. Interarea Oscillations

Figs. 18 and 19 also show that the damping of interarea oscillations in the system is more accurately simulated with the new governor modeling, compared with the previous modeling. In both the new and old model simulations in Fig. 18, the initial swings are less damped than the real system oscillations. However, for time periods greater than 15 seconds or so, the old model shows significantly greater damping compared with the new modeling and with system recordings. The effects of the new governor modeling upon oscillatory dynamics in simulation of the June 7, 2000 test shown in Fig. 19 are discussed in [2]. The simulation in Fig. 19 is clearly more accurate in the frequency and damping of oscillations with the new governor modeling. Oscillations in the WECC are a major concern and several studies have been performed [3]–[5]. Further work is ongoing using the new thermal governor modeling.

### D. Predicting the Effects of Large Generation Trips

With the new governor model, system frequency responses and intertie flows can be predicted more accurately for large generation trips. Fig. 20 indicates the expected response for the trip of two generators at the Palo Verde nuclear plant, the largest $N-2$ contingency used in WECC studies. Simulations made with the existing model predict only half the frequency dip obtained when using the new modeling (almost the same as an $N-1$ trip). Also flows through the COI intertie between the NW and California could be in error by a considerable margin during peak load operation with the existing modeling.

## V. Ongoing Work for Model Enhancement and Obtaining Owner's Validated Data

While the developmental work was performed exclusively using the ggov1 thermal turbine-governor model, it was clear that the new modeling approach is also applicable to existing thermal governor models, such as the ieeeg1 model [6], with the addition of load controller and base loading features. A new

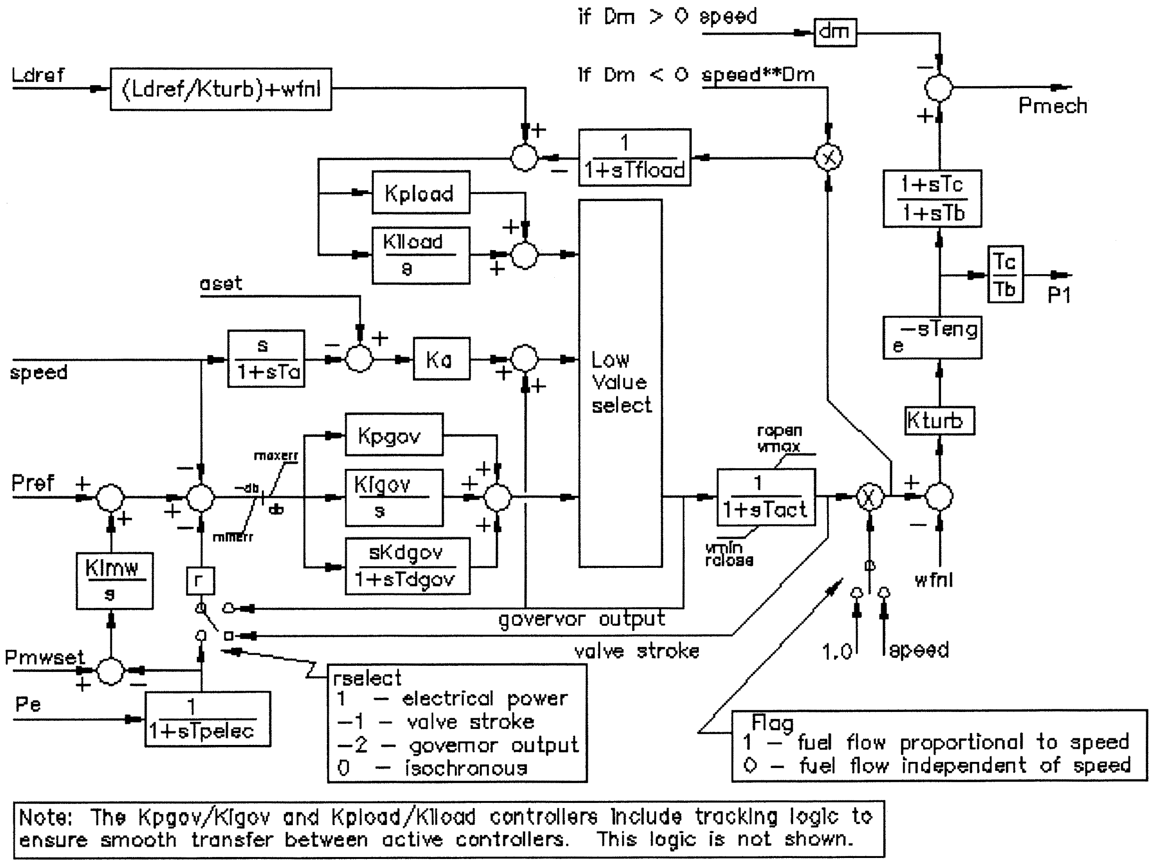


Fig. 21. Block diagram showing the basic relationships of the turbine-governor plant model ggov1 [8].

load controller model has now been developed that can be used with any turbine-governor model. Preliminary studies indicate that the results are close to those obtained with the ggov1 model described in this paper.

Ongoing work includes obtaining generator owners data for their new governor models that have been "validated" against recorded responses from actual events or tests. This validated governor data will form the new database in WECC for all dynamic stability studies.

## VI. Conclusions, Discussion, Further Work

A new thermal turbine governor modeling approach, based on improved simulation of base-loaded units and load-controlled units, has been developed for the WECC. Thermal plants embrace conventional fired steam, nuclear steam, and simple cycle and combined cycle gas turbine plants. The development, validation and verification of this model went through an extensive study process that included validation to WECC system tests conducted on May 18, 2001 and June 7, 2000 as well as verification with respect to numerous large system disturbances. The new modeling approach has been recommended and approved for use in all planning and operation studies in the WECC.

While our interest as described in this paper was specifically to governing relating to the WECC, the Western Interconnection in North America, the general principles of the new thermal governor modeling approach clearly apply to all interconnections [7], large or small.

The following are some of the important impacts of the new thermal governor modeling on major system operation and planning studies:

- system frequency responses can be predicted more accurately for large generation trips;
- effects of large special protection system (SPS) operation on the system are more accurately simulated;
- improved modeling of hydro versus thermal generation responses is achieved;
- a more accurate prediction of intertie flows and dynamic limits is obtained.

The following studies are expected to benefit from the use of the new thermal governor model

- study of frequency responsive reserves (FRR) and spinning reserves;
- dynamic voltage stability studies;
- underfrequency and load shedding studies involving large generation trips and/or system islanding;
- methodology described in this paper provides the basis for establishing a more accurate post-transient powerflow methodology for studies involving large generation trips.

Further work on turbine-governor modeling is ongoing and planned in the following areas

- to obtain validated data from generator owners for the new thermal governor model;

- to obtain data from owners of units without governor and exciter models for which typical models were included in the validation studies performed;
- to achieve more accurate modeling of hydro plants to the correction of frequency including the development of new models for Kaplan turbines and nonlinear hydro turbine characteristics;
- to include modeling of AGC for studies extending to long periods, such as system oscillations and dynamic voltage stability.

## Appendix
## Thermal Turbine-Governor Model

As has been the case in the modeling of thermal turbine-generators for 50 years, the ggov1 model represents both a turbine (or engine) and its governor. As in essentially all of the older models (such as ieeeg1), the turbine/engine model in ggov1 [8] is not a detailed thermodynamic treatment but is a very simple linear transfer function representation. The ggov1 model extends the older practice by controlling this simple turbine/engine model with the governor and in addition with a basic representation of a supervising control, and a basic managing control as shown in Fig. 21.

The governor in ggov1 is a proportional-integral-derivative (PID) element typical of modern practice. It allows the droop feedback signal to be either valve position or electrical power and hence can be used to represent either modern equipment or older mechanical-hydraulic governors.

The supervising element of ggov1 normally represents a load limit. The origin of the load limit that this element would represent varies widely from plant to plant. In a steam turbine plant it is most likely a limit whose value is decided on and set by the operator based on his or her intentions regarding operation of the plant (for example, the operator may limit the plant output for a few hours if he is having difficulty maintaining condenser vacuum because of trouble with a cooling water circulating pump). The limit level is stated in terms of turbine power by the parameter. It is essential to note that in most cases this parameter is not a direct statement of a limit value, but rather, it states the turbine power that corresponds to the limit. In gas turbines, it is the exhaust temperature limit.

The load management element of ggov1 is intended to represent the power controller that is the control room operator's primary interface with the turbine in many power plants. The load controller representation of ggov1 is a reset element that, when active, works to regulate the turbine power to the value of its setpoint, Pmwset. In ggov1 this power setpoint is initialized to match the initial condition turbine power. If Pmwset is not adjusted during a simulation, the load controller will countermand the action of the governor to return the turbine to its initial condition output. The model recognizes that the power setpoint of the plant may be adjusted during the period of a grid simulation. Adjustment of the setpoint may be a manual action of an operator or may be implemented by the receipt of signals from a grid AGC system.

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