Maintaining Power Grid Reliability Through Individual Unit Stability

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Abstract

The grid in the United States and Canada is the largest interconnected electrical system in the world, and as a result, is normally very stable. However, occasionally voltage and frequency excursions do occur and may be very broad and threaten the integrity of the larger grid. With the addition of significantly growing wind and other "non-dispatchable" types of generation, there is a greater potential for a less stable grid. It is optimal to have all available units participate in stabilizing both the frequency and voltage. Because of the characteristics of most excitation systems, all synchronous generators should be able to assist in voltage control. A significant portion of the frequency control is accomplished by hydro-electric generators because the fuel, water under pressure, is immediately available and these units are normally not operated at their maximum output unlike many coal and natural-gas powered units. Kestrel Power Engineering and American Governor Company have performed successful testing and tuning of generators throughout the United States and Canada for compliance to North American Electric Reliability Corporation (NERC) requirements. This paper presents the method by which several types of hydroelectric units were prepared and tested.

Introduction


Figure 1 - Hydro-Electric Generation in Tennessee

New laws and regulations for meeting the increase in energy needs, while protecting security and the environment, has created a frenzy of adding wind, wave and other "green" source generators to the system. The first ocean wave energy project was licensed by the Federal Energy Regulatory Commission (FERC) in December of 2007, and more wave power projects are planned. While wave power is in the future, wind power has been steadily increasing over the last several years. Wind and waves are not controllable power sources. General environmental conditions creating the wind and wave may be forecast. This, however, is an inexact science and actual power delivered will vary dynamically. Other generators on the grid are expected to compensate, and there is a great deal of concern "about whether sufficient ramping capability exists to help manage the increasing variability that results from significant wind penetrations."[1] Forecast and hourly load variations from wind remain the responsibility of grid operators and/or Automatic Generation Control (AGC) systems. "Transient or unexpected load variations may require operators to limit wind output for brief periods in order to maintain system reliability."[2] In this environment, the importance of the voltage and frequency control characteristics of conventional generating sources, especially hydroelectric, will increase. This paper presents a method to ensure that existing hydroelectric generation will provide optimal automatic dynamic control focusing on frequency transients on the grids. This solution is extremely easy and cost effective, may be performed on any vintage of control, and requires minimal down time on the machine.

Figure 2 - Wind and Fossil Fuel Generation

Background

From the beginning of power generation for mass use, the stability of both frequency and voltage has been important. The devices using this power were, however, particularly robust when it came to deviations in both of these factors. As the grid grew larger and generation technology better, the grid became much more stable. In response to a more stable grid, some devices using the power became less tolerant of frequency and voltage deviations. For many years it was assumed that the sheer size of the system would assist in the stability of the entire system. Recently performance of the system has required people to re-focus on the control and stability of generation connected to the grid. Some types of generators can help with grid stability and some cannot. Several forms of generation have restrictions. Coal and nuclear rely

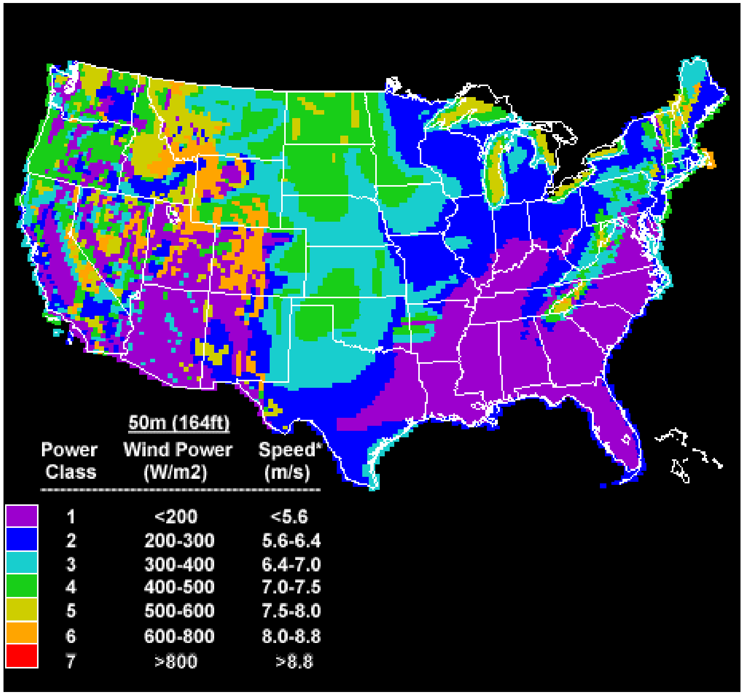

Figure 3 - Wind Availability in the United States

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[1] National Renewable Energy Laboratory (NREL), June 2007, Impact of Balancing Areas Size, Obligation Sharing, and Ramping Capability on Wind Integration

[2] The Northwest Wind Integration Action Plan, March 2007, published by Northwest Power and Conservation Council

on steam generation. This process has inherent limitations on the size and duration of frequency response. Both steam and gas turbines have temperature restrictions and may not be able to ramp quickly to assist in frequency changes. Wind and tide generation are not capable of controlling the fuel source to provide frequency control and have the greatest possibility of increasing frequency deviations. According to the Northwest Wind Integration Plan:

"When wind energy is added to a utility system, its natural variability and uncertainty is combined with the natural variability and uncertainty of loads. This increases the need for flexible resources such as hydro, gas-fired power plants, or dispatchable loads to maintain utility system balance and reliability across several different timescales. The demand for this flexibility increases with the amount of wind in the system. …. Conceptually, the cost of wind integration starts low, as the amount of variability introduced by a small amount of wind is virtually lost in the larger fluctuations of loads. As the amount of wind increases, the effects of wind variability dominate the effects of load variability, and flexibility needs to be added to the system in direct proportion to the growing wind penetration. Access to large amounts of existing system flexibility, such as that provided by the region's hydroelectric resources, can help minimize the costs of wind integration and postpone the need for investments in other sources of system flexibility."[2]

Changing Regulations

Due to the relative stability of frequency control on the large interconnected North American grids, little attention has been paid to the present state of the regulations for frequency control. Data published in 2004 identified a declining frequency response on the Eastern interconnection based on historical data dating back a decade.[3] An updated version of that information is shown in Figure 5 below. For each year the average size of disturbance (MW) required to produce a frequency change of 0.001 Hz is displayed. On a system where the connected generation and load is growing should exhibit a positive slope indicating that the grid is becoming more tolerant to generation/load mismatches.

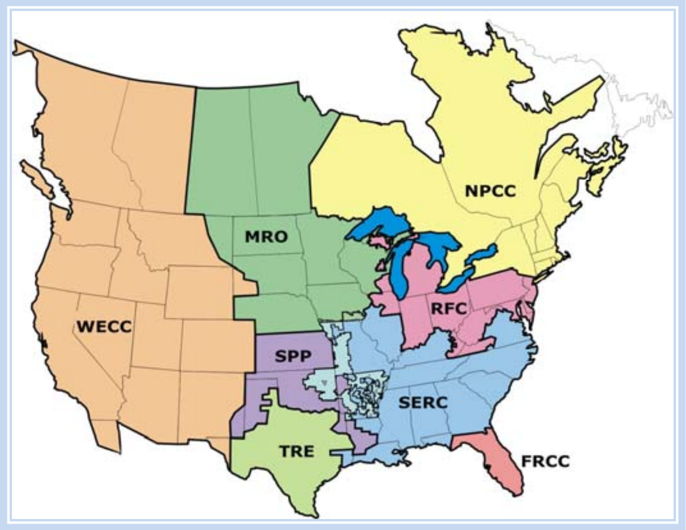

Figure 4 – NERC Regional Entities

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[3] North American Electric Reliability Corporation (NERC), April 6, 2004, Frequency Response Standard White Paper

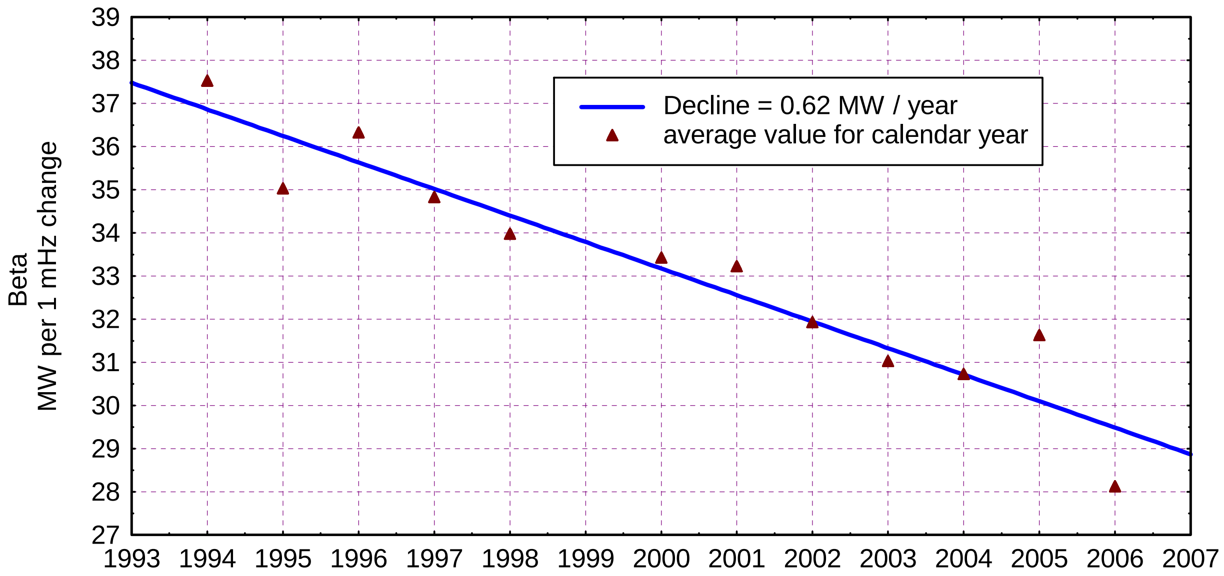

Figure 5 - Decline in Frequency Response on the Eastern Grid

Based on these results and similar observations by power system operators and regulators, the rules on frequency control are currently being rewritten to identify the reasons for the declining response. Included in the present guidelines are; units must have speed governing, be set to 5% speed droop and be stable while responding immediately and sustainably to frequency deviations. The regulations do not dictate specific settings for stability control.

Hydro's Role

Hydroelectric generation is the best solution for maintaining the grid frequency. There is an existing fallacy that the momentum and size of the hydro units would result in a slower response. In fact, hydro units can respond very quickly and have been providing a significant contribution to the control of frequency for a century. The properties of the hydro's fuel source, water, make it the best solution for the issues presented. The water is immediately available and, in most cases, easy to control. "Because hydro resources are fast, flexible and do not consume fossil fuels, they are in many ways ideal economic and environmental sources of flexibility to manage the variability of wind energy."[2] In addition to the quick response, energy is stored for later use while the other green sources of power are generating.

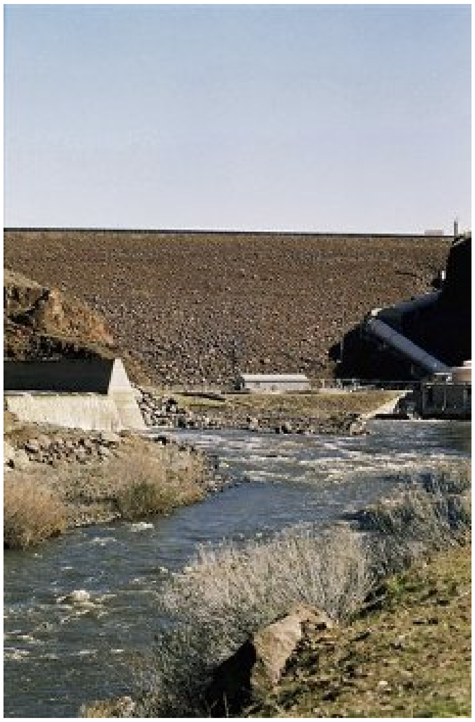

Figure 6 - Irongate Dam in Northern California

Methodology for Preparing the Unit for Participation

Preparing the unit for grid frequency control participation consists of three elements: determine restrictions on the unit's ability to contribute, perform regular maintenance on the unit, and tune the unit for good on-line response. All three elements must be performed for the unit to operate properly. These steps may be completed on any type or vintage of governor.

Preparing Unit

- *Determine Restrictions*
- *Perform Regular Maintenance*
- *Tune for Stable Response*

The first step is to determine if there are any restrictions on the unit that would prohibit the unit from moving the gates, or other water handling devices, to follow grid frequency. Some canal fed and most "run of river" units have flow limitations to minimize impact on the environment. Impulse turbines are restricted by the speed of the needles. The deflector would need to be in the stream to provide quicker response to transient load variations. Some energy must be deflected away from the turbine and is wasted during normal operation. The unit selection criteria are based on the restrictions mentioned above. The availability of water, response timing and size of generators should also be used to determine each unit's type of response to an excursion. Even some restricted units can respond to small grid variations and enhance overall grid stability.

Second, the units must be well maintained. The following minimal criteria must be in place for the unit to control well:

- A clean oil system with adequate pressure.
- Minimized lost or binding motion in all wicket gates, or other water controlling devices.
- Properly maintained and calibrated control and feedback devices (position and speed feedback, speed and position request, etc.).
- Clean, slop and friction-free oil handling devices, links, levers and bearings in the governor.

Third, the unit governor must be tuned for good control both off- and on-line.

Two factors must be tuned on the governor system; Permanent and Temporary compensation. There are regulations for permanent compensation (speed droop) on units over 10 MW. However, there are only recommendations for temporary compensation. Permanent compensation determines magnitude of the response to an excursion. Temporary compensation determines the manner in which the unit will respond.

Permanent compensation, or speed droop, is used to allow multiple units to be connected to the same grid. Small, islanded grid systems will often have one large unit that is set to respond fully to frequency deviations while the remaining units react to only a portion of the deviation. The larger unit must be able to correct for the remaining deviation for the system to be stable. Large grids present a challenge. There is no one single unit that can correct the entire system deviations due to the size of the grid and distance the power is transmitted. All units are operating with speed droop and are expected to respond to frequency deviations in a predictable manner. However, if the units were to react aggressively, the result could be too much correction. The temporary compensation, if not properly tuned, could cause additional instabilities, regardless of the permanent compensation setting.

Two Compensation Factors

Permanent → How Much

Temporary → How

There are three factors (gains) in the temporary compensation that will determine how the unit reacts: Proportional, Integral and Derivative. Every governor, regardless of vintage or type, possesses these tunable values in one form or another. Traditionally, these values have been tuned very carefully to allow the unit to be synchronized to the grid in a safe and stable manner. Once the unit circuit breaker is closed, these values, or just the integrating value in the case of mechanical governors, are often "opened up" to load and unload quickly. However, as the grid becomes more variable, it has become important to have a more controlled response from all available units. Units of all vintages have been tested and re-tuned for more stable on-line response, while still allowing acceptable loading and unloading rates.

Units Require Tuning of Temporary Compensation Both Off-Line and On-Line for Good Stability

Figure 7 depicts a Woodward Mechanical Cabinet Actuator that is connected to the grid prior to maintenance. The sluggish gate movements in response to frequency variations show that the governor requires both maintenance and tuning.

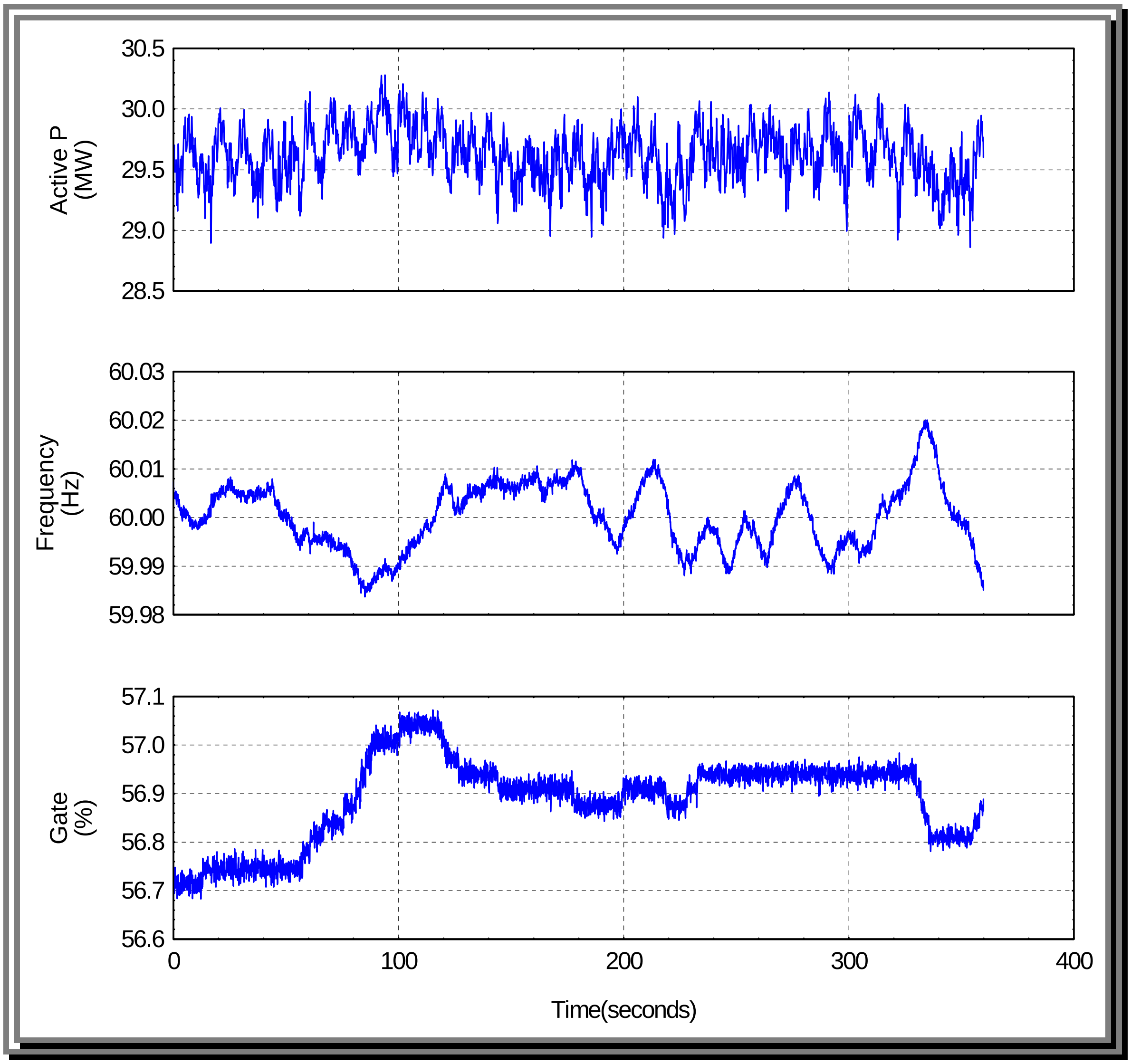

Figure 7 - Mechanical Cabinet Actuator Prior to Maintenance and Tuning

Figure 8 depicts the same Mechanical Cabinet Actuator after maintenance and proper tuning. Now the gates are dynamically responding to variations in the frequency of the grid and are contributing to the grid stability.

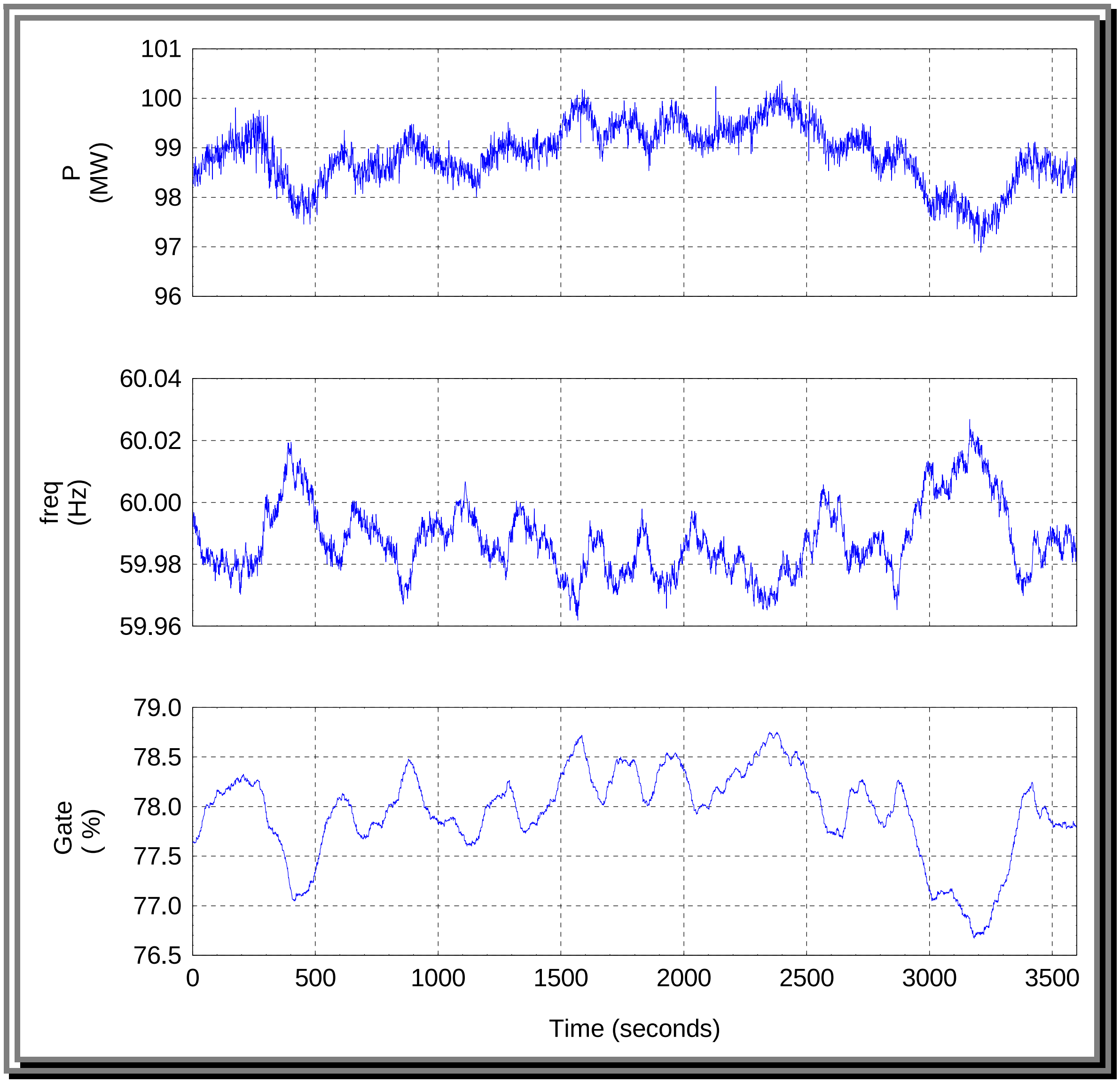

Figure 8 - Mechanical Cabinet Actuator after Maintenance and Tuning

Figure 9 depicts a Woodward Mod II Analog Governor after maintenance and proper tuning. Once again the gates are following the frequency in a stable manner. This particular unit was housed with multiple others in a large power house. The more dampened gate movement, when compared to the Mechanical Cabinet shown previously, is intended to allow all of the units in the power house to contribute in a stable manner.

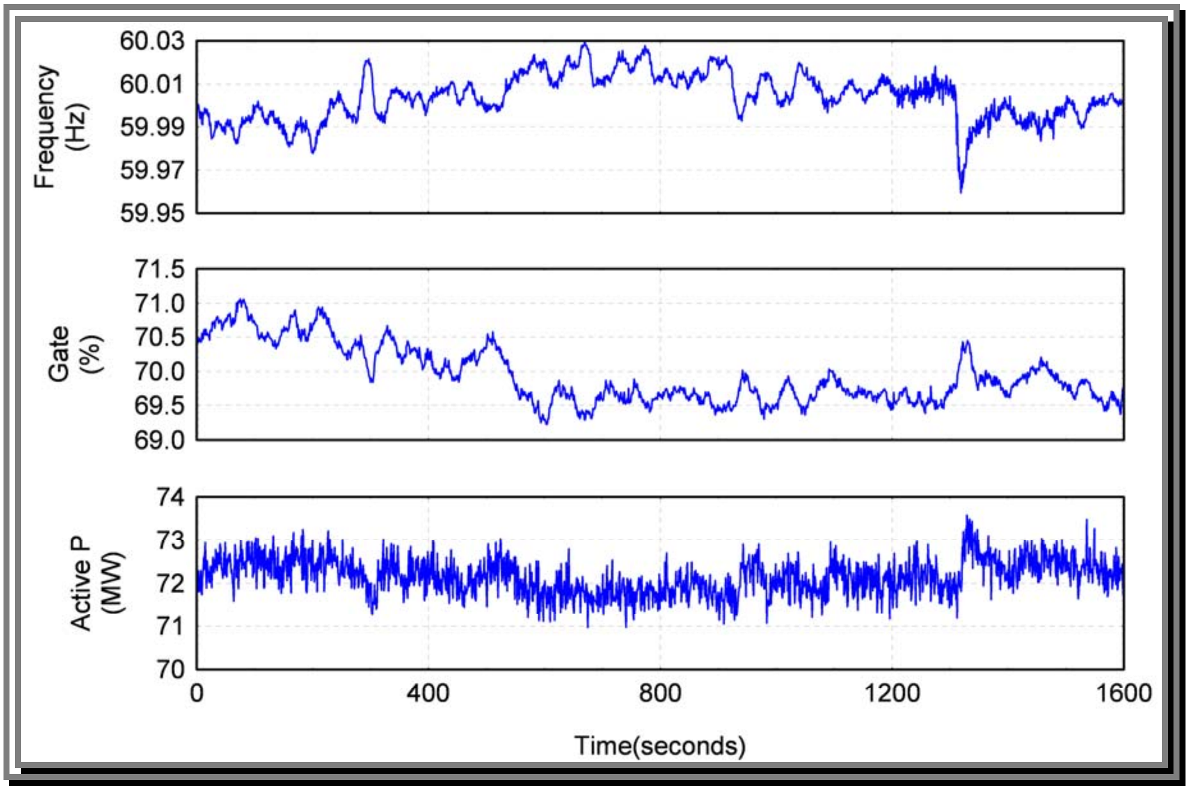

Figure 9 - Analog Governor after Maintenance and Tuning

Testing

Testing the unit for adequate response is a relatively simple process. The test procedure does require some readily available, specialized equipment, including a recorder, electronic gate feedback, speed detection and MW detection. The entire test procedure should take approximately four hours, including setup and removal of equipment. The test consists of monitoring gate position, unit speed, or system frequency when on-line, and power output simultaneously. An example procedure is listed below with the typical time frame.

Figure 10 – Unit Test Equipment

Task	Steps	Estimated Time
Setup	• Record governor settings • Connect slide wire to servomotor • Connect recorder to PT/CT secondary's near governor • Connect step input from recorder to governor	2 Hours (initially, less for sister units)
Open Circuit Measurements	• Offline speed adjustment calibration • Speed reference step tests	30 minutes
Load rejection	• Partial load rejection from 20% of rated load.	15 minutes
Online Measurements	• Droop measurements • Speed reference step tests • Deadband measurement (as time permits) • Gate limit/Water starting time test	1.5 Hours
Removal of equipment	• Disconnect and move to next unit	1 Hour

Conclusion

New sources of generation are being added at an increasing rate that could decrease the stability of the grid. While regulations evolve, individual organizations can take the steps required to properly adjust their hydro units to improve grid stability with minimal cost and down time. The operational parameters of each unit need to be analyzed to determine the proper type of response to excursions, proper maintenance needs to be performed, and the units tuned and tested for stable control. With these factors in place, it may be possible to add more wind and wave power than studies have projected.

Authors

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