VOLTAGE REGULATOR WITH DUAL PID CONTROLLERS ENHANCES POWER SYSTEM STABILITY

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Abstract – High performance excitation systems have become very important as limited generation capacity and consumer needs for power continue to increase.

This paper introduces a voltage regulator with two PID controllers. The fast controller is utilized with the power system stabilizer in service and the slow controller is utilized when the power system stabilizer is disabled. Transfer from one controller to the other is automatically accomplished without a bump when the power system stabilizer status signal changes. Two sets of gains are optimally tuned: less loop gain for use without a power system stabilizer (PSS) to maintain stable generator performance and higher gain for use with a PSS to optimize the transient and dynamic performance after a disturbance.

This concept was commissioned, and the actual test results indicate its effectiveness.

1. INTRODUCTION

In the 1950s and into the 1960s, many power generating plants were equipped with continuously acting automatic voltage regulators. As the number of power plants with automatic voltage regulators grew, it became apparent that the high performance of these voltage regulators had a destabilizing effect on the power system. Power oscillations of small magnitude and low frequency often persisted for long periods of time. In some cases, this presented a limitation on the amount of power able to be transmitted within the system. Power system stabilizers were developed to aid in damping of these power oscillations by modulating the excitation supplied to the synchronous machine.

Transient stability is primarily concerned with the immediate effects of a transmission line disturbance on generator synchronism such as a transmission fault. Clearing the fault may result in the removal of one or more transmission elements from service and, at least temporarily, weakening the transmission system. Simultaneously, it causes the generator rotor to accelerate with respect to the system, increasing the power angle. When the fault is cleared, the electrical power is restored to a level corresponding to the appropriate point on the power angle curve. This causes the unit to decelerate, reducing the momentum the rotor gained during the fault. If there is enough retarding torque after fault clearing to make up for the acceleration during the fault, the generator will be transiently stable on the first swing and will move back toward its operating stable point. If the retarding torque is insufficient, the power angle will continue to increase until synchronism with the power system is lost.

Power system stability depends on voltage regulator response and the clearing time for a fault on the transmission system. A fast and powerful excitation system is recommended to improve the power transfer capability of the synchronous machine. However, the fast voltage regulator can be detrimental to the dynamic stability unless means are added to restore damping using a power system stabilizer.

Digital technology is being used for excitation systems from large steam and hydraulic turbines down to small diesel driven generators. Recently some articles covering features, functions, benefits, models, etc. of the digital excitation systems have appeared in the literature [1,2].

In this paper, practical concerns will be discussed regarding transient and dynamic stability and the benefits of a dual PID controller that help optimize performance.

2. THE NEED FOR DUAL AVR CONTROLLERS

Maintaining power system stability depends on many factors, including excitation system speed of response and forcing capacity, as well as relay tripping time. Increased field forcing capability and decreasing response time increases the margin of rotor stability. This effect is illustrated in Figure 1, where the lower Curve A, represents the power angle curve of a lower forcing, slower response excitation system. Comparing the area under the curve for acceleration when the electrical load is less than the mechanical load to the area under Curve A for deceleration clearly shows that a machine under the example condition will lose synchronism. For Curve B representing a faster, higher forcing exciter, the area under the curve where electrical power exceeds mechanical power is much greater, sufficient to allow the generator to recover from the rotor swing. This benefit is the source of the demand placed on generation engineers to install the fastest available excitation equipment with very high levels of positive and negative forcing to secure the highest level of immunity to transient loss of machine synchronism.

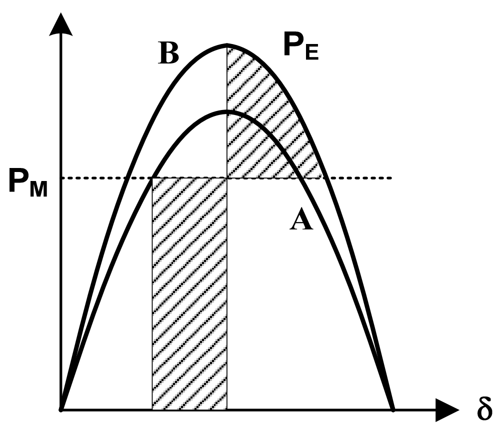


FIGURE 1: Effect of High Initial Response Excitation

While fast excitation systems provide tremendous benefits to transient stability following large disturbances to the system, the benefit may be outweighed by the impact of the excitation system on damping the oscillations that follow the first swing after the disturbance. In fact, a fast responding excitation system can contribute a significant amount of negative damping to oscillations, because it can reduce damping torque. Thus, an excitation system has the potential to contribute to small signal instability of the power systems while the voltage regulator with very high gain can be detrimental to the dynamic stability [5]. Such high gain cannot be used for practical operation if the PSS is not in service. This includes cases like the rough loading zone of a hydro turbine or steam turbine generator where the PSS may need to be disabled, a device failure, and/or maintenance testing of the generator.

To alleviate the concern, historically, compromises were required in the AVR controller gain settings to ensure a stable voltage regulator response with and without the power system stabilizer, or a transfer to manual control. None of these compromises offers desirable operation for optimum system response. Thus, it is desirable to have a fast controller with the power system stabilizer and a slow controller without the power system stabilizer.

Another option includes the use of two voltage regulator controllers, each having separated PID gain settings tuned to provide optimum performance depending upon the power system stabilizer being active or inactive.

3. VOLTAGE REGULATOR WITH DUAL PID CONTROLLERS

In the past, an analog voltage regulator approach to providing a dual controller scheme would have been very complex, and would have required sophisticated analog logic for switching gain groups. Tuning techniques would be very intense and cumbersome to derive appropriate settings for the dual stability groups. Furthermore, a switching between stability setting groups may not have always been bumpless [9]. In the digital world, available technologies simplify the implementation of a dual PID setting group and speed commissioning utilizing interface startup software. DECS-400 is a digital voltage regulator designed to utilize the cost advantage of digital electronics [3,4]. It is implemented with the state of the art techniques using two embedded microprocessors to perform the various control functions of the excitation system. It utilizes the digital PID controller with the sampling time of 4 msec.

As shown in Figure 2, dual PID controllers are implemented into the automatic voltage regulator. DECS-400 is capable of storing two sets of parameters and making an automatic and bumpless, on-line transfer from one PID gain set to the other when the power system stabilizer status signal changes. A slow response controller is utilized when the stabilizer is off, while a fast controller is used when the power system stabilizer is in service.

The digital regulator allows adjustment of most of the time constants and gains within the regulator. This provides a system that can be tuned over a wide range of machine dynamics. The method for designing dual PID gains for the digital excitation control system has been presented in earlier papers [3,4].

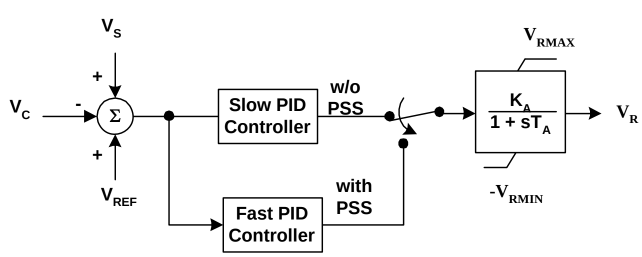


FIGURE 2: DECS Regulator with dual PID controllers

4. POWER SYSTEM STABILIZER

A power system stabilizer is designed to add damping to the generator rotor oscillations by controlling its excitation using a supplemental stabilizing signal. To supplement the generator's natural damping, the stabilizer must produce a component of electrical torque that opposes changes in rotor speed. Various types of power system stabilizers were reviewed for damping local mode oscillation [7]. PSS function is designed based on the integral-of-accelerating-power as illustrated in the block diagram of Figure 3. It matches the IEEE Type PSS2A dual input power system stabilizer model.

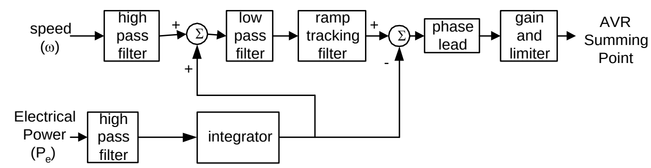


FIGURE 3: Dual Input Power System Stabilizer

5. EXCITATION SYSTEM PERFORMANCE TESTS

The digital excitation system was designed for a hydro turbine generator rated for 137 MVA at 0.8 P.F. Excitation requirements were such that the static exciter could provide not less than 450 Vdc field forcing, with 70% rated terminal voltage into the main field and with a nominal field current of 812 amps at rated load, rated power factor. Each static exciter consisted of 100% functional redundant digital controllers whose output tracks the primary and backup controller to ensure bumpless transfer. Each digital controller was implemented with two PID setting groups, allowing for different settings selectable based upon the PSS being active or inactive.

Initial testing was performed to determine suitable PID gain settings based upon off-line voltage step responses. For each PID setting group, 2% voltage step responses were performed to derive final settings for unit operation. Figure 4 illustrates response and voltage characteristic after a 2% voltage step was performed with a fast PID setting group intended for use with the power system stabilizer being active. For this system, the power threshold was set for 25% power. The proportional gain was set such that it was 10 times higher than the integral gain with an overall loop gain set for 35. The loop gain considers the overall gain of the generator, the digital controller and the amount field forcing. Table 1 provides performance results for Figure 4, which illustrates the voltage step response with the fast gains implemented. Note the voltage rise time is 0.072 seconds for the 2% voltage step change with an 11% voltage overshoot.

Slower PID settings were established for use with the non-active power system stabilizer: a slower PID setting group was utilized for stable operation. This was accomplished by reducing the overall loop gain from 35 to 25. Figure 5 illustrates the unit's performance with a 2% voltage step change off-line while Table 2 highlights unit performance. Note, the rise time has increased to 0.1 seconds while the voltage overshoot is reduced to 4%.

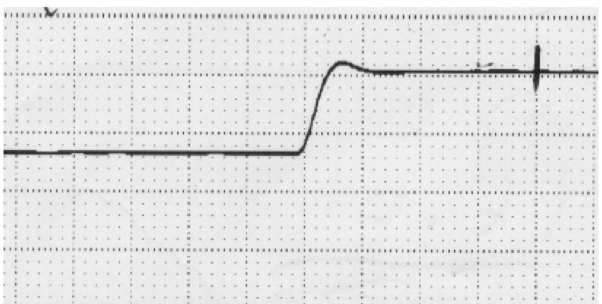


FIGURE 4*:* AVR 2% step response with Kg=35, Kp=200, Ki=20 (25 msec/Maj Div)

TABLE 1
Performance of off-line step response with Kg=35, Kp=200, Ki=20 (200 Vac/Maj Div)

Voltage step change	Rise time	Recovery time	Voltage overshoot
2%	0.072 sec	0.232 sec	11.07%

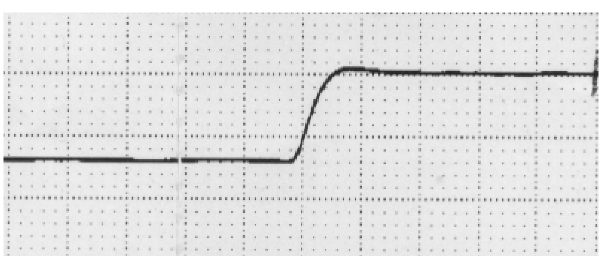
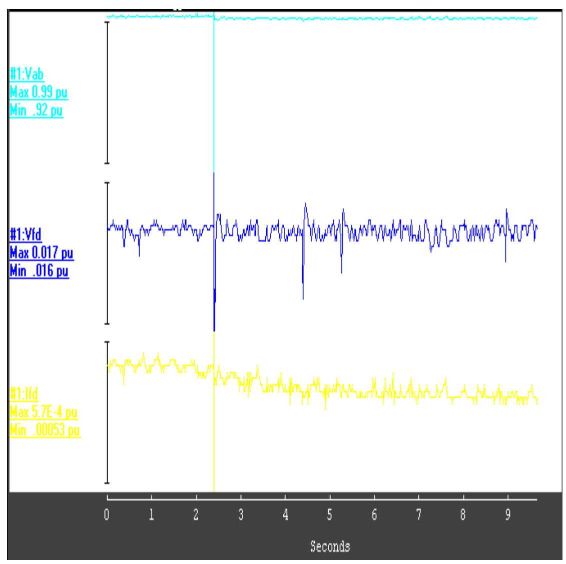


FIGURE 5: AVR 2% step response with Kg=25, Kp=200, Ki=20 (25 msec/Maj Div)

TABLE 2
Performance of off-line step response with Kg=25, Kp=200, Ki=20 (200 Vac/Maj Div)

Voltage step change	Rise time	Recovery time	Voltage overshoot
2%	0.1 sec	0.4 sec	4.06%

It was important that the transition to the alternate PID setting group be bumpless to avoid any unacceptable disturbance to the system. Figure 6 illustrates performance between the two gain sets. At time equal 4 seconds, the transfer is made from the fast PID gain group to the slower gain group with no visible affect in generator voltage as shown in the top graph. Field voltage indicates more stable operation after transfer to the slower gains.



fast gain ← | → slow gain

FIGURE 6*:* Transfer between fast and slow gain

After PID analysis was complete, the machine was paralleled to the bus, and performance was again reviewed between the two setting groups. The first test highlights unit performance with the slow PID setting group with a 2% voltage step change and the machine operating at 80 MW.

Figure 7 shows the AVR with a +2% voltage step response using the slower gain group at 80 MW without the power system stabilizer. Generator Megawatts, Mvars and generator voltage response are illustrated before and after the system disturbance. A stable generator voltage and Mvars are experienced, but machine MW swings initially then dampens after a few cycles, providing for a stable machine. Overall performance was deemed acceptable without the use of the PSS.

Figure 8 illustrates the generator performance using the fast PID setting group with the power system stabilizer disabled. Note how the machine MWs are unstable when the 2% voltage step change is introduced. Without the supplemental control of the power system stabilizer, the excitation system cannot remain in the fast PID setting group for safe operation.

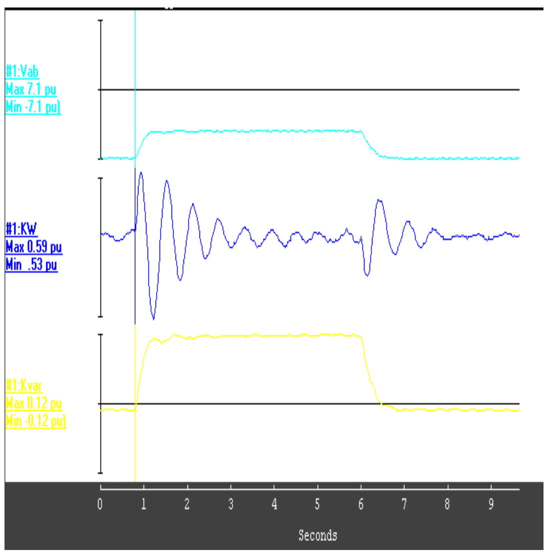


FIGURE 7*:* AVR 2% voltage step response with slow gain and with PSS disabled

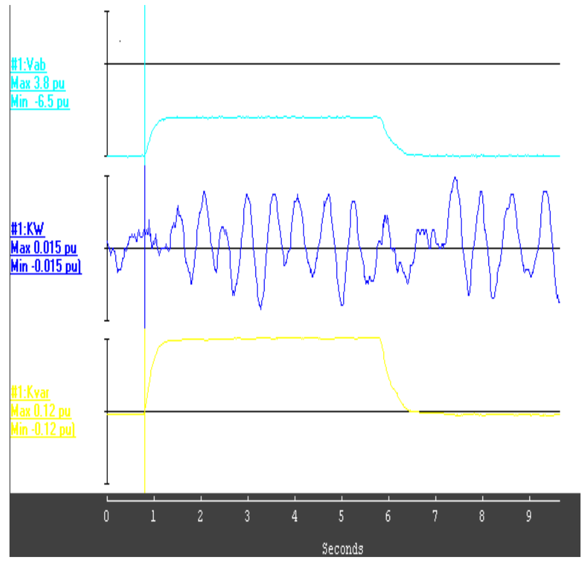


FIGURE 8*:* AVR 2% voltage step response with Fast gain and with PSS disabled

Figure 9 again shows performance with the fast PID setting group, except now the power system stabilizer has been enabled. The power system stabilizer is tuned to provide optimum performance with the fast voltage regulator gain set. Note how unit performance favorably changes when the 2% voltage step change is introduced. The machine's power swings once and immediately stabilizes, illustrating a very well-behaved system.

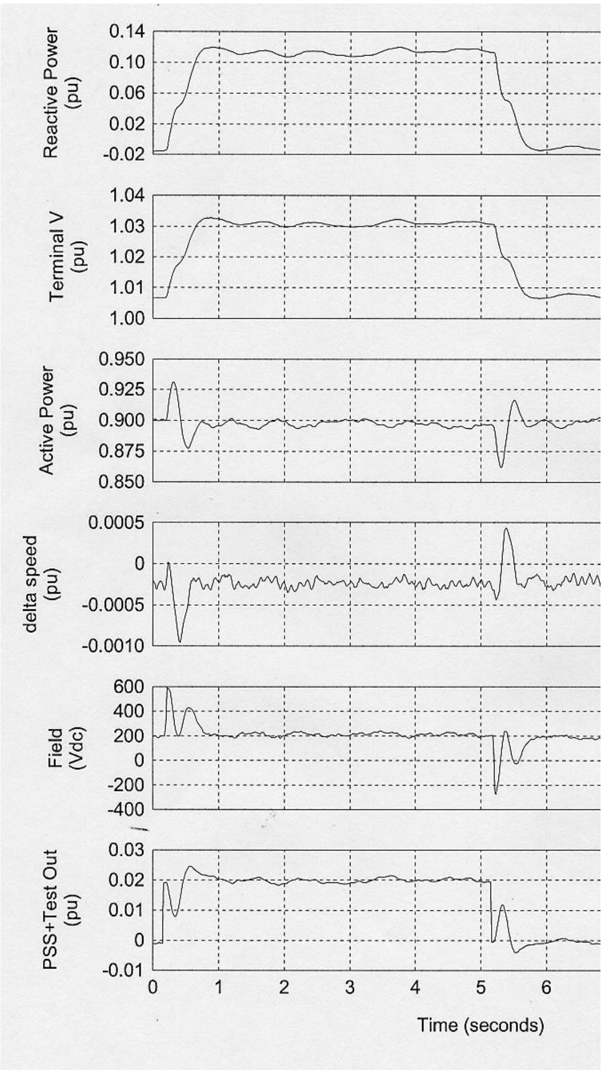


FIGURE 9: AVR 2% step response with fast gain and PSS at full load.

6. CONCLUSIONS

A general discussion of the issues related to the need for dual AVR controllers has been addressed. The performance data indicates very desirable features in the supplemental control functions that can benefit both transient and dynamic stability with use of very aggressive gain sets for performance. Test data demonstrates that, with the dual PID setting group, performance does not need to be compromised when the power system stabilizer is disabled.

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