# Recent Developments on Generator Excitation Control System
## — Introduction of Digital AVR and Power System Stabilization Technology —

Yoshihiro Kitauchi
Takashi Shirasaki
Kunitaka Hayashi
Minoru Banjo
Satoshi Kitamura

*OVERVIEW: In recent years, the scale of power systems has been expanding, and with that expansion stable power supply and smooth power system operation is becoming increasingly important. In particular, because system stability tends to decrease as the power system moves toward higher capacity and longer distances in power transmission and wider-area operations, and as the constant power, non-linear load generated by air conditioners and other such equipment increases, ensuring and increasing power and voltage stability becomes an even greater problem. One measure for increasing stability is to improve the main circuits by raising the voltage or employing series capacitors in power transmission lines, but the generator exciter control method, which makes use of a CD-AVR (compact digital automatic voltage regulator), PSS (power system stabilizer) and PSVR (power system voltage regulator), is attracting attention because of its high cost advantage. Hitachi, Ltd. has implemented these generator exciter controls with the HIACS-7000 System, which uses the latest 32-bit RISC (reduced instruction set computer) processors, to realize a practical high-speed, highly reliable exciter system that is suitable for stable operation of a power system.*

### INTRODUCTION

AS a result of the increasing capacity and expansion in operating area of power system, together with the increasing constant power load, there is a tendency for both power stability and voltage stability to decline in power system, and this decline has become a pressing issue. Concerning power stability, in particular, the suppression of the 0.3- to 0.5-Hz long-period power perturbation that occurs between power systems is being examined closely as a problem that should be solved, in addition to the 1.0 Hz or so power perturbation that occurs between conventional generators.

Here, we describe the latest digital exciter system for generator control that is particularly effective in improving system stability.

### POWER SYSTEM STABILITY AND EXCITER CONTROL

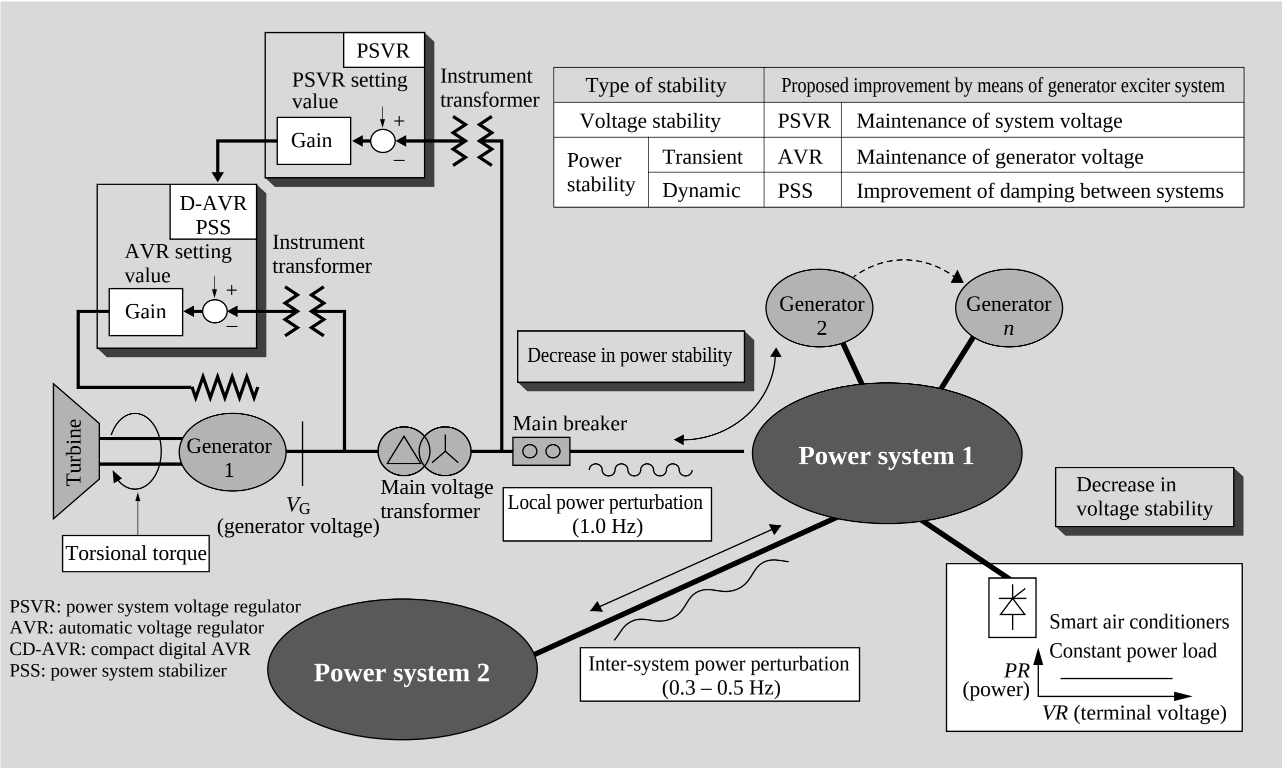
Power system stability involves, voltage stability, in which a constant voltage can be restored and maintained even when changes in load occur, and power stability, in which the power perturbation that arises between generators that are operating in parallel is quickly suppressed and a constant power can be maintained. It is necessary to sufficiently guarantee both types of stability, taking the most severe operating conditions into consideration.

The approaches to improving power system stability include methods of improving the main circuits by increasing the system voltage, construction of additional power transmission lines, installation of series capacitors, installation of SVC (static VAR compensator) and so on and the method of generator exciter control.

Although the main circuit improvement approach is a fundamental measure, the scale of reconstruction is very large. The control approach, on the other hand, makes it possible to extract the maximum capability of the generator by improving the control algorithm when digital control equipment is used, which has a very large economical effect.

### CD-AVR (COMPACT DIGITAL AUTOMATIC VOLTAGE REGULATOR) AND PSS (POWER SYSTEM STABILIZER)

In order to accomplish exciter control for power stability, it is necessary to accurately and rapidly measure various types of power perturbation data, including the effective power ($P$), internal frequency




| Type of stability | | Proposed improvement by means of generator exciter system | |
|---|---|---|---|
| Voltage stability | | PSVR | Maintenance of system voltage |
| Power stability | Transient | AVR | Maintenance of generator voltage |
| | Dynamic | PSS | Improvement of damping between systems |

*Fig. 1— Power Systems and Stability.*
*Stability includes power stability and voltage stability. Improving both of these is important to the operation of a power system.*

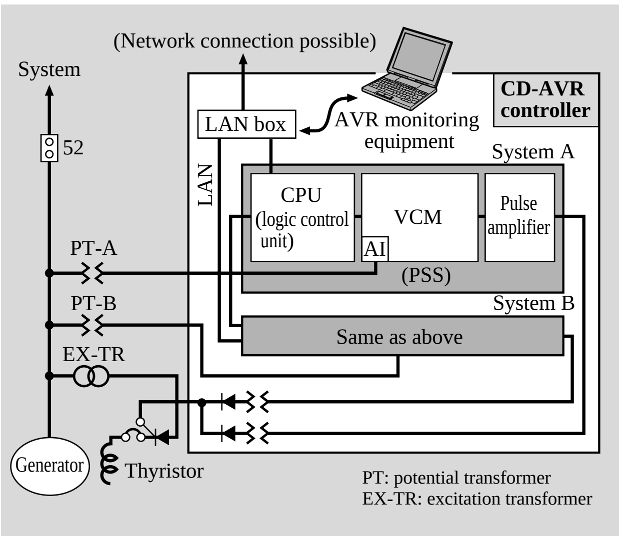



*Fig. 2— Example of a Parallel Redundancy System CD-AVR.*
*Employing the VCM makes it possible to construct a compact, highly reliable redundant system.*

(*fq*), and rotational speed (ω). It is also necessary to implement a control algorithm that can use those input signals to guarantee control for a wide range of power perturbation frequencies (0.3 to 1.5 Hz). Because fine control is difficult to achieve with conventional analog control methods, the HIACS-7000 system (Hitachi Integrated Autonomic Control System 7000), which makes full use of the latest 32-bit digital technology, was employed to develop a CD-AVR (compact digital automatic voltage regulator), and with that, the PSS was implemented in software.

To improve power system stability and maintainability by means of PSS, the following points were taken into consideration in the CD-AVR.

(1) Development of a compact VCM (voltage control module) that integrates an analog input (AI) for the instantaneous current value and high-speed voltage control implementation of the highly accurate, high-speed signal detection that is required for wide-area power stabilization control.

(2) Implementing a parallel redundancy system that takes advantage of the characteristics of thyristor control reduced the changes in voltage that arise when an abnormality occurs in one of the systems and the effects on the system compared to a stand-by redundancy system (Fig. 2).

(3) In human-machine systems, one-step operation for the setting of the control constants, the monitoring and recording of operating conditions, and alarm display from the window screen on the AVR (Automatic Voltage Regulator) monitoring equipment in the panel and enhancement of display format for on-line setting changes and the high-speed historical trend function,

so that the field testing and parameter tuning for installation of the system stabilizer, which will be particularly important in future, can be accomplished easily and without special testing instruments.
(4) Improved visibility by enabling the AVR monitoring equipment to make a one-to-one correspondence between the logic diagram and the control program enabled the easy maintenance and management through unified document management.
(5) Reduction of space requirements by 50% or more for the storage of the duplicate voltage control unit, pulse amplifier and monitoring equipment has been achieved.

Furthermore, the system can handle large-capacity generators of up to the 1,000-MW class and can be applied to update situations where installation space is particularly limited as well as to new plants.

Hitachi, Ltd. has installed CD-AVR for the No. Minato 2 generator (350 MW) of the Higashi-Niigata Thermal Power Station and the No. 3 generator (825 MW) of the Onagawa Nuclear Power Station, both belonging to the Tohoku Electric Power Co., Inc.

## PSS

The PSS method that is currently widely used is based on the signal $\Delta P$ formula ($\Delta P$-PSS) with the effective power as the input. This method is applied to suppress the local power perturbation between generators, which has a power perturbation frequency of about 1.0 Hz.

For the low-frequency perturbation that occurs between power systems in wide-area operation, however, there is little system perturbation information included in the active power, so $\Delta P$-PSS has little effectiveness. As a solution to that problem, $\Delta P$+$\Delta\omega$ PSS, which uses the internal frequency (*fq*) or the rotational speed ($\omega$) as well as the active power is effective for low frequencies, was used. However, $\omega$ includes turbine and generator system axle torsion fluctuation information as well as system perturbation information, so consideration must be given to the use of a notch filter or other such device when this input is used.

## MULTI-INPUT PSS

As a generator exciter control method for increasing power stability, $\Delta P$-PSS is widely used, but recently, the $\Delta P$+$\Delta\omega$ (or $\Delta f$) method of PSS has been made practical for the purpose of wide-area stabilization. However, to guarantee stability in long-distance power transmission systems and to achieve control performance that is not easily affected by changes in system status (robustness), the multi-input PSS method, in which the VAR, $\Delta Q$, is added to the $\Delta P$+$\Delta\omega$ method, was jointly developed by the Tohoku Electric Power Co., Inc., the Central Research Institute of Electric Power, and Hitachi, Ltd.

Because, $\Delta Q$ is quite unaffected by system operating conditions compared to $\Delta P$ and contains the angle of the internal phase difference ($\Delta\delta$) between the system and the generator in nearly constant proportion, it is effective for suppressing the 0.3- to 0.5-Hz low-frequency power perturbation that occurs between power systems.

In multi-input PSS, a circuit for improving transitional stability (*v* circuit) is added to achieve an excellent effect for both transitional stability and

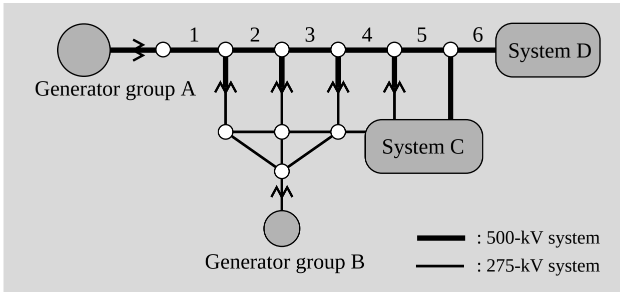



*Fig. 3— 12-Generator Model System.*
*A conceptual diagram of the wide-area power system model for evaluating stability is shown.*

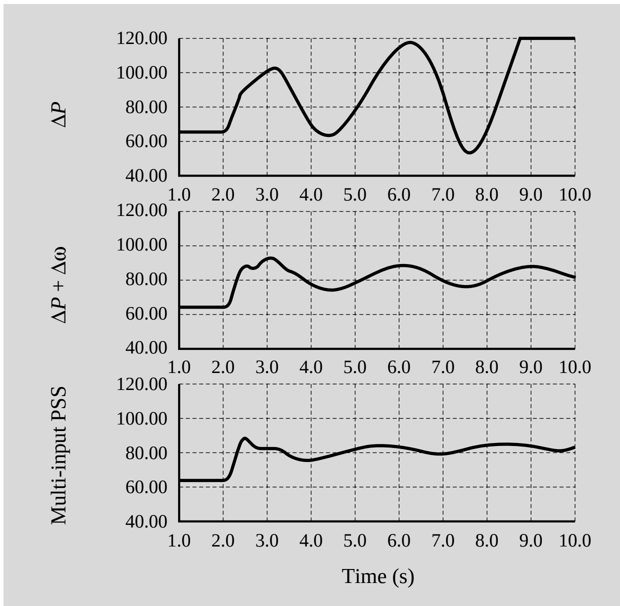



*Fig. 4— Example of Experimental Results on Power Stability Improvement (Change in Phase Difference Angle after Excluding System Short-circuit Accidents).*
*With multi-input PSS, there is little change in the phase difference angle after exclusion of system short-circuit accidents, and there is an excellent increase in both transition stability and operation stability.*

operating stability.

In addition, we were able to confirm that almost the same effect can be obtained if the frequency signal, f, of the internal induced voltage of the generator is used in place of the ω signal. The frequency signal can be detected directly by calculation from the voltage and current. Thus there is no need for equipment that has an electromagnetic sensor, and so multi-input PSS can be implemented even in hydroelectric generators, where the installation of an exciter pick-up is difficult.

Concerning the improvement in power stability by application of multi-input PSS compared to the conventional methods, the results of verification experiments performed using the 12-generator model system that is illustrated in Fig. 3 are presented in Fig. 4.

The verification experiments were performed with a model of the actual system. The model combined a test board that employs a commercial D-AVR and a RTDS (real-time digital simulator).

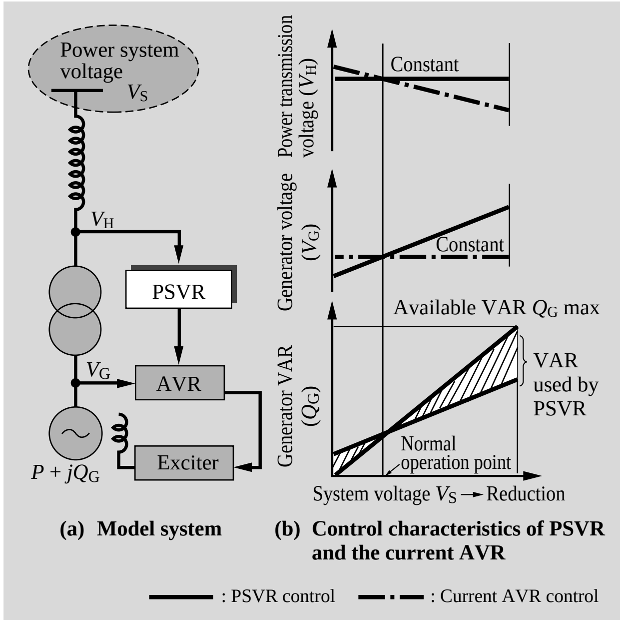



*Fig. 5— PSVR Control Characteristics at the Time of a System Voltage Drop.*
*Using the PSVR allows effective use of the VAR supply capability of the generator.*

## VOLTAGE CONTROL EQUIPMENT FOR IMPROVING THE VOLTAGE STABILITY OF POWER SYSTEMS

### The Need for Voltage Stability and the Trend in This Area

The trend is toward severe voltage stability requirements for power systems due to the increase in load from air conditioners, etc., which has voltage characteristics that approach constant power, and the expansion of the 275-kV cable system in urban areas, and the emergence of long-distance power transmission systems with concentrated large-scale power sources.

The generally used measure for voltage stability against increases in load is to install a power capacitor or synchronous phase modifier at the load termination. As a power-source-side measure, on the other hand, the Tokyo Electric Power Company, Hitachi, Ltd., and others have conducted joint research on the PSVR (Power System Voltage Regulator), which uses generator exciter control to accomplish power transmission voltage control at the high-voltage side of the step-up transformer of the power station. This PSVR has been installed in the entire 500-kV system, which contributes most to the key system voltage stability, and to the power generation stations that are connected to the 275-kV system and operation has begun.

### PSVR Principle and Effect

The relationship of the power transmission voltage, the generator voltage and the VAR when the system voltage drops is shown in Fig. 5 (b) for the case of PSVR control and the case of control by the current AVR, based on the one generator versus an infinite bus system model such as shown in Fig. 5 (a). As we see in Fig. 5 (b), in the normal system voltage operating range, both control methods result in almost the same operation status, but when the system voltage drops, the PSVR provides constant control of the power transmission voltage, so the generator voltage is automatically increased by the amount of decrease in the reactance of the step-up transformer and control to increase the VAR is performed. The current AVR control, on the other hand, controls the generator voltage to a constant value, so there is little VAR generation and the transmitted voltage drops in proportion to the drop in system voltage. In the end, the purpose of the PSVR is to improve the overall system voltage stability by causing the generation of VAR as shown by the inclined lines in Fig. 5 (b) so as to maintain a high and constant power transmission voltage system to ameliorate drops in system performance.

Simply installing a PSVR makes it possible to make effective use of a VAR supply of over 400 Mvar in the example of a 1,000-MW class generator. It also has a great economical merit of reducing investment in facilities by making it possible to eliminate the costs of power capacitors and synchronous phase modifiers.

## PSVR Equipment

The PSVR combines techniques for stable operation, such as preventing reduction in stability due to the power perturbation that is associated with voltage control gain and adding restriction functions for suppressing the change in VAR among generators and limiting generator operation to within the operating limits.

When the PSVR is installed, the equivalent impedance of neighboring devices becomes small, so highly accurate control is required. In addition, highly accurate operation planning for the power system as a whole is also required for changes in the power transmission voltage setting and so on. For those reasons, the latest PSVR is composed of the HIACS-7000 advanced high-speed digital controller produced by Hitachi, Ltd. Anticipating the need to change settings in accordance with changes in system configuration and system operating conditions, the device was designed so that the user can easily change the control constants by using the ten-key pad on the setting panels to enter setting values.

## CONCLUSIONS

We have described the D-AVR + PSS and PSVR methods as specific proposals for improving power system stability by means of generator exciter control.

Concerning power system stability, there is a need for development of new automatic parameter setting technology that would make it possible to cope with the advances in system operation from future globalization and the increased diversity and complexity in the load on the generator that comes with it, as well as to cope with changes in system conditions due to temporal considerations, such as daytime, nighttime and the seasons.

Automatic tuning methods based on PSS output and the perturbation waveform of the internal induced voltage have already been investigated. We intend to continue to accumulate knowledge from experiments with actual machines and operating data and to apply that knowledge in the future.

## REFERENCES

(1) Y. Kitauchi, et al., "Experimental Verification of Multi-input PSS with Reactive Power Input for Damping Low Frequency Power Swing," IEEE Transactions on Energy Conversion Vol. 14, No. 4 (December 1999).

(2) Y. Kitauchi, et al., "Simulation Experiments on a Multi-input PSS Prototype for Suppression of Long-period Perturbation," Proceedings of the National Convention of the Institute of Electrical Engineers of Japan, 6-276 (1999), in Japanese.

(3) M. Amano, et al., "Exciter System Identification and Automatic Tuning of Linear Combination-Type Power System Stabilizers Using Prony Analysis," Transactions of the Institute of Electrical Engineers of Japan, B, 7-8 (1998), in Japanese.

(4) T. Michigami, et al., "Development and Application of a New Generator Excitation Method (PSVR) for Improving Voltage Stability," Transactions of the Institute of Electrical Engineers of Japan, B, 7-8 (1998), in Japanese.

(5) T. Kimura, et al., "Latest High-Reliability Supervisory and Control System for Power Stations," *Hitachi Hyoron* **82**, 2,159-164 (2000), in Japanese.

## ABOUT THE AUTHORS

Yoshihiro Kitauchi

*Joined the Central Research Institute of Electric Power Industry (CRIEPI) in 1986, and was assigned to the Power System Laboratory. He is currently engaged in research on power system analysis, control, and operation. Mr. Kitauchi is a member of the Institute of Electrical Engineers of Japan, and can be reached by e-mail at kitauchi@criepi.denken.or.jp.*

Takashi Shirasaki

*Joined the Tohoku Electric Power Co., Inc. in 1978, and was assigned to the Research and Development Center. He is currently engaged in research on power system analysis, control, and operation. Mr. Shirasaki is a member of the Institute of Electrical Engineers of Japan, and can be reached by e-mail at w780231@tohoku-epco.co.jp.*

Kunitaka Hayashi

*Joined the Tokyo Electric Power Co., Inc. in 1991, and was assigned to the Bulk Power Network Operation Planning Group of the Power System Operation Department. Currently, he is engaged in the design of PSS and PSVR equipment. Mr. Hayashi is a member of the Institute of Electrical Engineers of Japan, and can be reached by e-mail at t0726695@pmail.tepco.co.jp.*

Minoru Banjo

*Joined Hitachi, Ltd. in 1973, and now works at the Information Control Systems Division of the Power &Industrial Systems. He is currently engaged in the design and development of generator exciter control devices. Mr. Banjo is a member of the Institute of Electrical Engineers of Japan, the Sensing Instrument Control Engineers of Japan, and the Information Processing Society of Japan, and can be reached by e-mail at mbanjo@omika.hitachi.co.jp.*

Satoshi Kitamura

*Joined Hitachi, Ltd. in 1964, and now works at the Information Control Systems Division of the Power & Industrial Systems. He is currently engaged in work on generator exciter control. Mr. Kitamura can be reached by e-mail at kitamura@omika.hitachi.co.jp.*