Line drop compensation, high side voltage control, secondary voltage control — why not control a generator like a static var compensator?

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Abstract: Generators typically regulate terminal voltage via automatic voltage regulator and exciter equipment. The desired high side (transmission side) voltage schedule is usually maintained by the power plant operator or by slow SCADA-type process control computers.

Power system dynamic performance, however, can be improved by faster regulation of the transmission voltage.

Contrasted to generators, static var compensators are designed specifically for transmission voltage regulation. The transmission voltage is directly regulated at high speed. Total SVC and medium voltage component reactive power ratings are referred to the transmission side. All medium voltage equipment are designed to support the transmission side reactive power and voltage regulation requirements. The droop (slope) setting is usually small compared to generators regulating terminal voltage.

This paper introduces the panel session on secondary voltage control. I outline various methods for tighter high side voltage control, with emphasis on control of hydro generation in the U.S. Pacific Northwest.

Keywords: power system stability, voltage collapse, automatic voltage regulator, secondary voltage control, high side voltage control, line drop compensation

I. INTRODUCTION

This paper introduces the panel session on Power Plant Secondary (High Side) Voltage Control. I also describe voltage control practices and proposals in the U.S. Pacific Northwest.

Generators typically regulate terminal voltage via automatic voltage regulator and exciter equipment. The desired high side (transmission side) voltage schedule is usually maintained by the power plant operator or by slow SCADA-type process control computers.

Power system dynamic performance, however, can be improved by faster regulation of the transmission voltage.

Panelists will present and debate various methods of transmission voltage control, with emphasis on voltage control by power plants. The controls are secondary to automatic voltage regulators, which most commonly control generator terminal voltage. (AVR line drop compensation is also within the scope of the panel.) Secondary controls may be local to the power plant, providing an outer loop to regulate transmission-side voltage and equalize reactive power output of individual generators; this is by adjustment of individual generator AVR setpoints. For optimization, emergency boosting, and coordination of closely-coupled power plants, the transmission-side voltage schedule or setpoint may come from a control center based tertiary loop. Control is generally hierarchical, with secondary voltage control being an order of magnitude slower than AVR, and tertiary control being an order of magnitude slower than secondary control. As described in one panel paper, the primary and secondary loops may be combined for fast regulation of high side voltage similar to a SVC.

Practice and terminology for secondary voltage control in some European countries is to regulate voltage at a remote "pilot" bus rather than power plant high side busses. The pilot bus is usually an EHV load-area bus, and the method allows sensitive coordinated reactive power dispatch of several plants in a "voltage control area."

Digital technology and modern communications facilitate advances in voltage and stability control [1].

With regard to long term voltage stability, many references describe prior work [2,3].

II. OPEN ACCESS AND INDUSTRY RESTRUCTURING

Open access, and our industry restructuring into generation, transmission, and distribution companies raises anew questions on power plant voltage and reactive power control. The point of interconnection is usually at the transmission side of the generator step-up transformers. For both technical and commercial reasons, it's logical to focus on the transmission side for network voltage control and reactive power interchange.

Restructuring requires industry interconnection standards and ancillary services mechanisms. NERC (North American Electric Reliability Council) is developing required standards, policies, and guides [4]. NERC Planning Standard III.C.S2 states: "Generators shall maintain a network voltage or reactive power output as required by the transmission system operator within the reactive capability of the units. Generator step-up and auxiliary transformers shall have their tap settings coordinated with electric system voltage requirements."

NERC Planning Standard III.C.S1 requires generators to operate in "automatic voltage control mode unless

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approved otherwise by the transmission system operator." With this mandatory requirement, ancillary service arrangements could reimburse generation companies for reactive power and reactive "energy" produced during heavy load conditions or absorbed during light load. Reimbursement could be for production or absorption outside a deadband, say, 0.98 power factor leading or lagging at the point of interconnection.

II. POWER PLANT VOLTAGE CONTROL

Bulk power system voltage control is primarily provided by excitation control of generators. Continuously acting automatic voltage regulators (AVRs) have been standard for the past 50 years. From generator manufacturer and power plant viewpoints, regulation of terminal voltage is natural. Terminal voltage regulation ensures generator voltage is within ±5% of rated voltage, protects generator in the case of load rejection, and helps in regulation of power plant auxiliary voltage. Terminal voltage control is simpler than transmission side control when multiple generators exist at a power plant (reactive droop compensation is used when generators are paralleled at their terminals). Digital AVRs and digital secondary control loops, however, facilitate more complex, higher performance control.

A. Line Drop Compensation

For tighter regulation of transmission voltage, line drop compensation may be used. Line drop compensation is a connection option of automatic voltage regulators. Regulation speed is the same as the terminal voltage regulation, resulting in improved transient angle and voltage stability. Of course, slow long-term voltage stability is also improved. Reference 5 describes simulation results where 50% line drop compensation at nine power plants significantly improved long-term voltage stability in the Portland, Oregon load area. The improvement was similar to adding a 460 MVAr, 550-kV capacitor bank in the load area.

Difficulties with line drop compensation arise when two or more generators are paralleled at their terminals. Panel session papers describe line drop compensation for this condition [6,7]. Again, digital AVRs facilitate more complicated control.

B. High Side Voltage Control

To meet transmission voltage schedules via AVR setpoint adjustment and to allocate reactive power output of units, power plants commonly use SCADA-type process control computers. The transmission voltage schedule is compared with transmission side voltage measurement. This control may be of the "shepherding" type involving sequential changes of AVR setpoints with subsequent control after waiting for response.

Panel session papers describe higher performance types of high side voltage control [6-8]. Other papers describe "secondary" voltage control involving remote voltage measurements [9,10].

C. Hydro Plant Control

Large hydro plants often include many relatively small units. The HV or EHV switchyard may be located several kilometers from the power plant. For example, the John Day plant on the Columbia River comprises sixteen 142 MVA units. There are four three-winding transformers, with two generators connected to each low voltage winding. Four 500-kV, 5.6 km power plant lines connect the power plant to the switchyard.

In such cases, line drop compensation is difficult because of multiple units per transformer winding.

High side voltage control is also difficult because telemetry is required from the switchyard voltage transformers to the power plant. An alternative is voltage transformer additions at the power plant, but this adds cost and there may not be space. Another possibility is transformer bushing potential devices, but accuracy is low.

Even when high side voltage measurements are readily available, the real-world accuracy of capacitive voltage transformers is around ±1% and averaging of several single-phase measurements is desirable.

The proposals in one of the panel session papers [6] are especially attractive for hydro plants.

D. LTC Generator Step-up Transformers

On-load tap changer step-up transformers facilitate voltage control under different system conditions [3]. For cost and transformer reliability reasons, however, LTC step-up transformers are not common in most countries.

III. TRANSMISSION AND DISTRIBUTION VOLTAGE CONTROL

Power plant voltage control should be coordinated with transmission and distribution voltage control. This section provides perspective for the panel session on power plant voltage control.

A. Transmission Voltage Control

Transmission voltage control is largely by mechanically switched reactor/capacitor banks; in special circumstances, static var compensators, STATCOMs, or synchronous condensers may be used. LTC auto-transformers are also used, most commonly with manual control through SCADA.

A strategy of many utilities is to apply shunt compensation to provide base reactive power, ensuring reactive power reserves at power plants for emergencies. This has allowed survival during a severe emergency [11].

Shunt compensation aids in optimal high and flat voltage profile for heavy load conditions. For heavy load conditions, BPA keeps 500-kV voltage around 540 kV at both power plants and receiving end substations.

Control can be local, manual through SCADA, and automatic centralized. Sophisticated local control of shunt compensation and LTC autotransformers is microprocessor based similar to thyristor switched compensation [2,3,12,13].

Shunt capacitor banks are low cost and have virtually zero losses. Modern all-film fuseless capacitor banks increase cost-effectiveness [14,15]. New techniques for multiple-step banks are developed [16,17].

BPA has fourteen 500-kV banks (up to 460 MVAr at 550-kV), fifty-three 230-kV banks (up to 168 MVAr at 241-kV), and numerous 115-kV banks.

Static var compensators or STATCOMs can be used in special circumstances for fast continuous control. Contrasted to generators, SVCs or STATCOMs are designed specifically for transmission voltage regulation. The transmission voltage is directly regulated at high speed. Total SVC and medium voltage component reactive power ratings are referred to the transmission side. All medium voltage equipment are designed to support the transmission side reactive power and voltage regulation requirements.

The droop or slope setting is usually small compared to generators regulating terminal voltage (2–5%). Thus better voltage coordination between SVCs/STATCOMs and generators can be obtained by generator high side voltage control. With terminal voltage control, the effective high side droop of a generator is approximately equal to the per unit step-up transformer reactance.

B. Distribution Voltage Control

Distribution voltage control is by LTC bulk power delivery transformers, distribution voltage regulators, and shunt capacitor banks. Control of shunt capacitor banks tends to be based on current or reactive power at stations, and on voltage near end of feeders. Local microprocessors, centralized computers, and various communication technologies are available for capacitor control (distribution automation). An interesting approach that eliminates a major mechanism of voltage collapse (load restoration) is to use capacitor banks rather that LTC transformers for distribution voltage control.

The policy of many utilities is to compensate distribution to close to unity power factor [11]. With industry restructuring, unity power factor at the point of interconnection of transmission and distribution companies may be the target.

IV. WIDE-AREA STABILITY AND VOLTAGE CONTROL AT BPA

BPA is developing wide-area stability and voltage control [18]. Figure 1 shows the concept. High accuracy positive sequence phasor measurements are used where available.

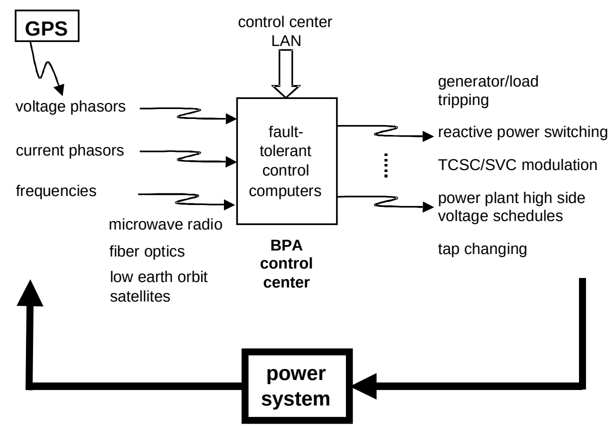

Fig. 1. Flexible platform for centralized control.

For high-speed transient stability control, fast generator tripping and 500-kV shunt/series compensation switching is proposed. For slow voltage control, 500-kV shunt compensation switching is proposed, plus power plant high-side voltage schedule changes.

Power plant voltage schedules are sent via the automatic generation control digital message. In a voltage emergency, power plants with reactive power reserves can be sent higher schedules to activate reserves to boost transmission voltages. This reduces reactive power losses, and increases line charging and shunt capacitor bank outputs. If power plant high-side voltage control does not provide droop, the control may also be used to equalize reactive power outputs of closely-coupled plants.

Another goal is to automate autotransformer tap changing, preventing circulating reactive power/current between parallel transformers at different stations.

Many of the components shown on Figure 1 exist, including phasor measurements, outgoing transfer trip signals for generator tripping and compensation switching, SCADA, control center LAN and digital AGC messages. Digital AGC messages include an emergency voltage control mode requesting power plant operators to bring all on-line and standby units to maximum reactive power capability. For the fast stability control, digital fiber optic communication is used for the phasor measurements. Fiber optic communication is more reliable and has smaller latency than alternatives.

With many input measurements and many outgoing signals, brute force redundancy is not planned. Failure of a single input signal or outgoing signal may degrade control, but not cause failure.

Synergy with other control center functions such as BPA's reactive power monitor [19] and voltage security assessment development is expected.

One scheme to equalize reactive power outputs of closely-coupled plants is being tested The power plants are Grand Coulee (7,111 MW, 24 units) and Chief Joseph (2,614 MW, 27 units). Both plants have units connected at both 230-kV and 500-kV, with autotransformers connecting the 230-kV and 500-kV busses. The two plants, approximately 52 km apart, are connected by two 230-kV lines and one 500-kV line. The high side voltage schedules are adjusted to equalize the MVAr/MW ratio (tan ϕ) of the four generating groups. A BPA control center alarm is given for high autotransformer reactive power flow, leading to manual tap changing through SCADA.

V. SUMMARY

Based on prepared papers and presentations, the panel session offers an opportunity to debate many options for improved power plant voltage control. Issues include terminology, control strategies and philosophies, impact of industry restructuring, and cost effectiveness of the various advanced controls.

The panel session also provides a starting point for the new CIGRÉ Task Force on Coordinated Voltage Control in Transmission Networks [20].

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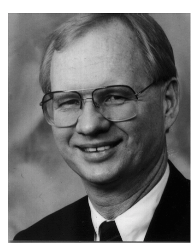

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