SECONDARY COORDINATED VOLTAGE CONTROL SYSTEM : FEEDBACK OF EDF

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Abstract: With power systems operating under tighter constraints, and closer to their actual operating limits, optimization of available margins becomes an increasingly critical concern, especially with regard to voltage stability and the management of static and dynamic reactive-power compensation systems.

With this aim, Electricité de France has developed and experimented a new secondary voltage control system, capable of coordinating compensation systems on a large scale.

This report presents the results of this new secondary voltage control system, which has been operating for more than two years in the west of France.

1. Overview

With power systems operating under tighter constraints, and closer to their actual operating limits, optimization of available margins becomes an increasingly critical concern, especially with regard to voltage stability and the management of static and dynamic reactive-power compensation systems.

Depending on the countries, different strategies are used for controlling and coordinating voltage maps. Primary voltage controls fitted on the generating units are commonplace, and do provide local control, but broader-scale voltage control, capable of coordinating compensation systems, is not yet widespread.

This report set out the results obtained with a new secondary voltage control system that has given full satisfaction to operators in western France over several years of service now. As well as discussing the improvements afforded by this new control system, we also outline specific advantages in the context of intensifying contractualization of exchanges between the electricity generating operators and the operator of the transmission network.

2. Voltage control mechanisms on the transmission network

Basically, voltage control on the French EHV (extra-high voltage) network operates at three different levels, which are temporally and spatially independent. Temporal independence means that the three control mechanisms do not interact; if they did, we would risk oscillation or instability. Details on this three-tier control system are widely available [1]:

- Primary control involves keeping generator stator voltages at their set-point values, by means of controls fitted to all the generating units. This performs partial automatic correction, within a few seconds, to compensate against rapid random variation in the EHV voltage.

- In its present form, secondary control is chiefly effected through the secondary voltage control (SVC) system, which has a time constant of a few minutes and compensates against slower voltage variations. Secondary control involves splitting the network up into theoretically non-interacting zones, within which voltage is controlled individually. SVC adjusts automatically the reactive power of certain generating units to control the voltage at a specific point (known as the pilot point) in the zone, this being considered representative of the voltages at all points in the zone. However, a faster and more precise type of secondary control system — Coordinated Secondary Voltage Control, or CSVC— has been in use in western France over the last two years, and is eventually expected to take over from the existing SVC system.

- At the highest level, tertiary control is applied to optimize the nationwide voltage map. This involves determining voltage set-points for the pilot points in order to achieve safe and economic system operation. Tertiary control is currently performed manually, but if automated it would have a time constant of around 15 minutes.

3. Principles and limitations of secondary voltage control (SVC)

Much has already been written about the SVC system [1], [2], [3], so, again, the following summary will be brief. Figure 1 shows the SVC block diagram.

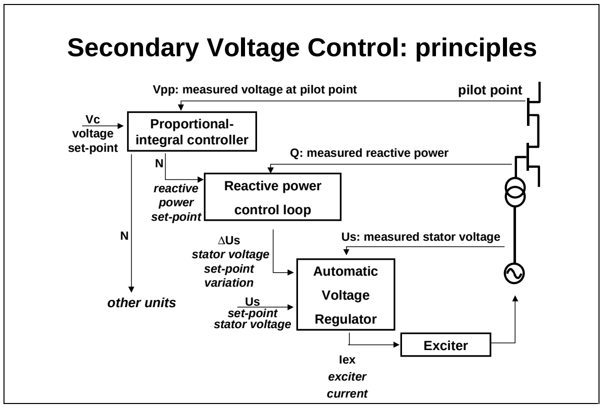

Figure 1: SVC block diagram

3.1. Basic principles of SVC system

The SVC system inputs the instantaneous voltage measured at the zone pilot point, compares it with the voltage set-point, and applies a proportional-integral law to determine a signal representing the reactive power level required for this zone. This signal is then used to determine a set-point for the reactive-power control loop of each generating unit. Steady-state reactive power generation is therefore aligned, with each generating unit contributing to the total reactive power requirement proportionally to its capabilities.

The SVC system integrates control of the HV capacitors, which means that the generating units retain a reactive power reserve available immediately in the event of incident.

3.2. Limitations of SVC system

Some limitations of the SVC system are structural:

- In some regions, coupling between theoretically independent zones has increased as a result of grid development subsequent to implementation of SVC. To avoid instability, we must therefore correct the number of zones or accept degradation in control dynamics.

- SVC requires reactive-power alignment of the generating units involved, but makes no allowance for excessive demand that might be made on certain units as a result of differences in physical proximity.

- The internal reactive-power control loop at generating-unit level is a destabilizing factor that can actually amplify the initial disturbance in the first few instants following certain incidents (generator drop-out, for example).

Other limitations are design-related:

- The system makes only partial allowance for operating constraints. For example, it does not fully integrate monitoring of permissible voltage limits or generating set operating limits.

- Control loop parameters are fixed, which precludes optimum allowance for operating conditions.

- The signal representing the required reactive power level varies at a rate that makes no allowance for generating unit response capabilities.

The SVC system has been in operation since the early eighties and has given satisfactory service despite the above shortcomings, some of which are mitigated by extensive operating experience. However, the structural limitations can only become more acute as the system grows, and there will come a time when renovation is required, to address equipment ageing. For both of these reasons it was decided to develop a more sophisticated secondary control system, known as CSVC, for "coordinated secondary voltage control". This is the system we shall be discussing in this article.

4. Coordinated secondary voltage control (CSVC)

In this article we give a general outline of the CSVC system. Fuller details are available in [3], [4] and [5].

4.1. Principles

Whereas the SVC system controls locally the voltage at a single pilot point, the CSVC system adjusts the voltage map for a whole region by controlling the voltages at a set of pilot points, using a set of set-point values.

In closed-loop mode, it computes fresh set-point values for the generator unit primary controls at 10-second intervals, by minimizing the following multi-variable quadratic function (1):

$$\begin{aligned}\min \Big\{ & \lambda_v \left\| \alpha (V_c - V_{pp}) - C_v \Delta U_c \right\|^2 \\ & + \lambda_q \left\| \alpha (Q_{ref} - Q\ ) - C_q \Delta U_c \right\|^2 \\ & + \lambda_u \left\| \alpha (U_{ref} - U\ ) - \Delta U_c \right\|^2 \Big\}\end{aligned} \qquad (1)$$

where:

α	Control gain.
Vpp, Vc	Measured and set-point voltage values at pilot points.
Q, Qref	Measured and set-point reactive power values at generating units.
U, Uref	Measured and set-point stator voltage values.
ΔUc	Vector of stator voltage variation.
λv, λq, λu	Weightings for terms in objective function: pilot point voltage, reactive power, and generator unit stator voltage.
Cv	Sensitivity matrices relating variations in pilot point voltage to variations in stator voltage (Network is modelled by sensitivity matrices for coordination between generating sites).
Cq	Sensitivity matrices relating variations in reactive power to variations in stator voltage.

Network and units constraints are taken into account at each computation step using the following equations.

$$\|\Delta U_c\| \le \Delta U_{\max}$$
$$a(Q + C_q \Delta U_c) + b\Delta U_c \le c$$
$$V_{pp_{\min}} \le V_{pp} + C_v \Delta U_c \le V_{pp_{\max}}$$
$$V_{ps_{\min}} \le V_{ps} + C_{vs} \Delta U_c \le V_{ps_{\max}}$$
$$V_{EHV_{\min}} \le V_{EHV} + C_v \Delta U_c \le V_{EHV_{\max}}$$

where:

a,b,c	Coefficients of straight lines representing operating diagrams for generator units (P,Q,U). These diagrams depend on the active power output by the generator unit.
Vpp, Vppmin, Vppmax	Measured, minimum and maximum voltage at pilot points.
Vps, Vpsmin, Vpsmax	Measured, minimum and maximum voltage at sensitive points.
V_{EHV}	Voltages computed at generator unit EHV output.

Sensitive points are nodes at which the voltage must be kept between upper and lower limits, though it is not controlled to a set-point value like at a pilot point.

The weightings in the objective function can be adjusted to suit different control policies, giving priority to keeping pilot point voltages at reference values (high voltage values, for example), or to keeping reactive power generation close to the lower limit in order to gain reactive power margins. In practice, the weighting for EHV voltages is higher than that for the two other terms.

The CSVC response time is about one minute.

4.2. Coordinated secondary voltage control in operation

Following a validation phase involving many simulations [4], conducted using Eurostag [6], it was decided to proceed with experimentation at the Western France control centre (CRES), which was known for its vulnerability to voltage stability problems. This control centre covers a geographical area that extends from the western-most tip of Brittany to south of the Paris region, and includes 80 EHV nodes (including 25 at 400 kV), 15 generating units and two synchronous compensators (Figure 2).

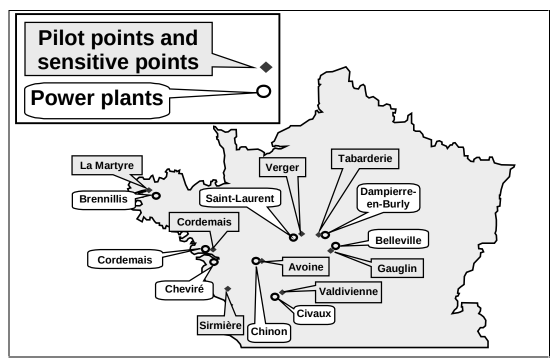

Figure 2: West France control centre map

Following startup in 1993, the experimental project went through several validation stages:

- Validation on test platform (micronetwork)
- Unit-by-unit open loop test
- Site-by-site closed loop test
- Operation under control of sub-region including three sites: Belleville, Dampierre and Saint-Laurent
- Gradual extension to other sites

This facilitated progressive installation prior to full-scale operation of all equipment at the Western France control centre.

Figure 3 shows the CSVC system architecture, which is made up as follows:

- Workstation (RSCT-D) located in control centre, responsible for real-time computation of set-point voltage variations (ΔUc) for input to generating units

- Digital transducer sensors (TN) fitted on generating units and substations
- Interface module (MI) for inputting computed ΔUc values to primary voltage control set-point signal for each generating unit
- Substation communication interfaces (RSCT-P), carrying signals from local digital transducers to RSCT-D
- Power plant communication interfaces (RSCT-C), carrying signals from local digital transducers and interface modules through to RSCT-D
- X25 communication network, conveying data (TM,TS) from substation and power plant interfaces to RSCT-D using ftp protocol
- RSCT-D connection to SCADA at computerized regional control centre (SIRC), for inputting data on transmission network topology and status
- Timekeeper at each site, for synchronization

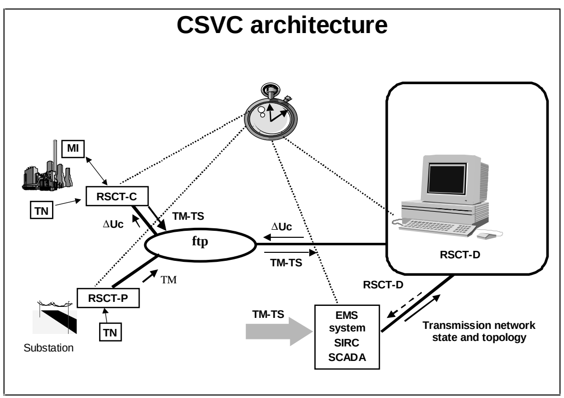

Figure 3: CSVC architecture

5. CSVC benefits

We note that the new control system has given full satisfaction to operators since it has been in service. CSVC system behaviour has given rise to no instance of instability, under normal or constraint situations (e.g. incident or sharp rise in load), though this was not always the case with the SVC. This successful performance obviously raises the issue of whether the CSVC system should be extended to offer nationwide coverage; functional studies are currently being conducted to examine this eventuality.

The experimental project feedback reveals three major benefits to the TNO.

a) The voltage map is more stable and precise (Figure 4), with less reactive power demand on the generating units.

b) Coordination improves the mobilisation of reactive reserves available from generating units, by making higher demand on the units closest to the perturbation. This represents a decisive advantage over the SVC system, which simply aligns the reactive power demand from all generating units, regardless of physical proximity. In addition, static compensation systems are under centralized control via the CSVC, whereas this capability was rarely used with the SVC system. And because CSVC evens out the control effort among generating units, it affords an overall increase in available reactive power reserves.

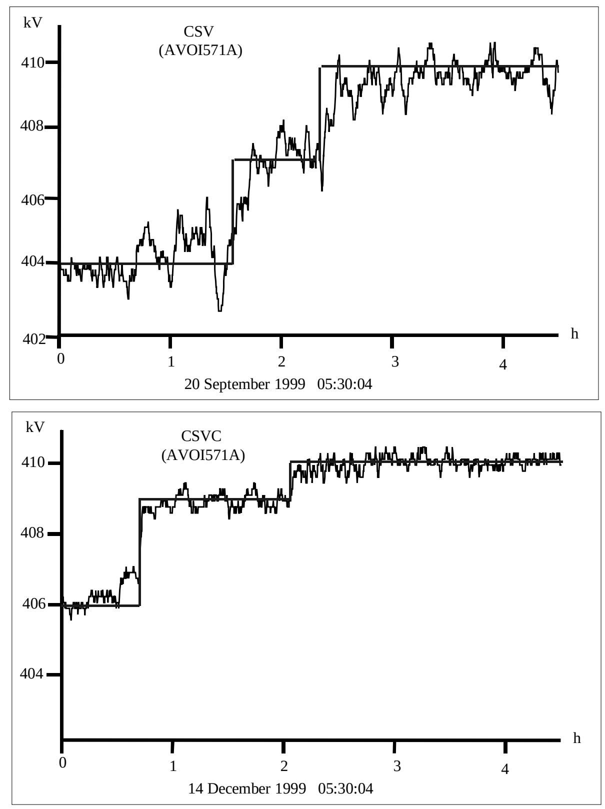

Figure 4: Voltage set-point and voltage response with SVC and CSVC

c) The CSVC system has a better dynamic response (Figure 4), and this enables operators to discontinue certain practices that were necessary to palliate against imperfections in the SVC system (e.g. anticipation of high variations in consumption).

Taken as a whole, these improvements enable the system to run closer to its actual operating limits, which is particularly pertinent under degraded network conditions following multiple incidents. Specifically, we note an increase in voltage collapse margin. By way of example, analysis shows that the CSVC system was instrumental in minimizing the impact of an incident in western Brittany in early 1998 (Figures 4, 5 & 6). By efficiently taking charge of voltage control across the CRES region as a whole, the CSVC system allowed the operator to focus full attention on the incident-stricken area (where control had become largely ineffective as a result of generating unit unavailability). Subsequent examination showed that in a similar situation the SVC system would have caused oscillations in voltage and reactive power among the generating units; this would definitely have distorted the operator's vision, and would very possibly have introduced further complications.

Chronology of 2 January 1998 incident:

1) loss of production leading to a EHV voltage drop to Avoine substation,

2) important load shedding leading to a EHV voltage rise (maximum value of 416 kV),

3) return of the EHV voltage to its setpoint value (410 kV) following the control system action.

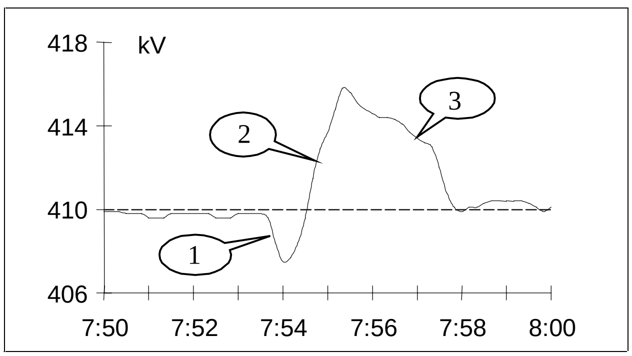

Figure 5: Avoine substation EHV voltage

Looking at the stator voltage evolution (Figure 6), the control system action firstly leads to a rise of the setpoint voltage stator (related to the EHV voltage drop consecutive with the loss of production), and in a second stage to a drop of this setpoint (connected this time to the rise of the EHV voltage consecutive with the load shedding).

We should also note four other improvements, which, though they do not bring immediate cost savings do greatly facilitate the operator's routine management tasks:

- Because of priority voltage management, set-point values are determined naturally under the CSVC system, without producing abnormal transients. This contrasts with SVC, which requires prior initialization based on an evaluation of generator reactive power, followed by a standby period of five minutes (during which the set-point voltage must not be modified) in order to allow reactive power alignment among the generating sets. And whereas CSVC control of a generating set requires no special precautions, SVC control can require the operator to perform corrective action on the control level, because of the transient induced in the primary voltage control system.

- Because CSVC offers higher measurement accuracy and valuable interface functions, operators appreciate its utility in monitoring voltage over the whole network.

- Reactive power management is improved because the operator can change the Qref value (reactive power reference value in optimization function) for one or more generating units in order to adapt operating points to a particular strategy.

- The operator can easily set a temporary minimum or maximum reactive power threshold for a given generating unit in order to allow for limitations on operating domain. The new condition will then be accommodated as an additional constraint in the optimization process. This capability offers two advantages: it makes for simple and optimum management of reactive power available at each instant, and it increases overall availability of generating units.

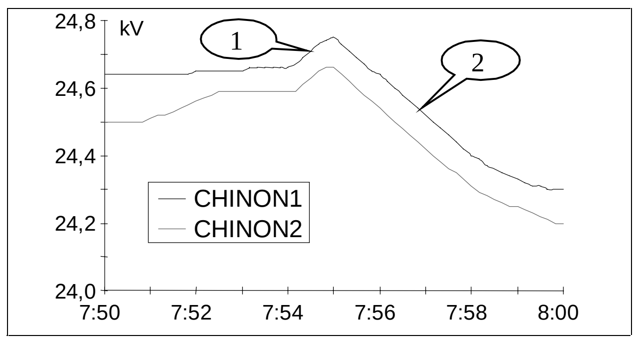

Figure 6: Chinon 1 & 2 – generators stator voltage set-point evolution -

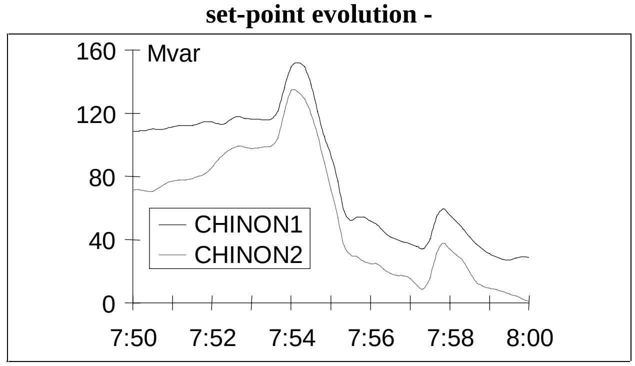

Figure 7: Chinon 1 & 2 – generators reactive power evolution -

In addition, higher measurement accuracy (chiefly a result of fitting precision sensors) facilitates accurate determination of actual generating unit limits, for closer adjustment.

All these benefits induce less strain on equipment, because reactive power variations are less pronounced.

Experience feedback shows that generating units have wider operating margins (i.e. distance from actual operating point to operating limit) with CSVC than with SVC. Specifically, CSVC increases the margin by 100 Mvar for nuclear plants, in terms of both supply and absorption of reactive power. Wider margins lead us to expect longer service life for some types of equipment.

6. Conclusions

Throughout an experimental period of over two years under full-time operation in western France, CSVC has given full satisfaction to operators, and has proved to offer many advantages over the existing SVC system. It responds faster and behaves more robustly under incident conditions, and it affords improved management of voltage and reactive power reserves, thereby improving system safety. Under CSVC, running the system closer to its actual operating limits is possible. Then the auxiliary devices integrated in a CSVC system facilitate accurate real-time monitoring of the reactive power supplied by each generating unit, and rapid location and estimation of available reserves.

Though the technical advantages of CSVC appear obvious, wide-scale extension to other regions (or, indeed, nationwide coverage) has not yet been decided. To prepare the way for forthcoming decisions on this matter, studies are currently being conducted into the advantages and disadvantages of alternative options (in terms of priority regions, location of pilot points, and control capabilities on hydroelectric generating plant, for example).

7. References

[1] J.P.PAUL, C. CORROYER, P. JEANNEL, J.M. TESSERON, F. MAURY, A. TORRA
Improvements in the organization of secondary voltage control in France
CIGRE, PARIS, 1990, rapport 38/39-03

[2] J.P.PAUL, J.Y.LEOST, J.M. TESSERON
Survey of Secondary Voltage Control in France: Present realization and investigations
IEEE Tr on power systems May 1987, vol. 2

[3] J.P.PAUL, J.Y.LEOST
Improvements in secondary voltage control in France
IFAC, BEIJING, 1986

[4] H. VU, P. PRUVOST, C. LAUNAY, Y. HARMAND
Improved Voltage Control on large-scale power system
IEEE, PORTLAND, SM 524-9 PWRS, July 1995

[5] P. PANCIATICI, F. BENA, P. PRUVOST, N. JANSSENS, J. DEUSE, M. STUBBE
Centralized voltage control: a key point for optimal operation of power systems.
CIGRE, PARIS, 1998, rapport 39-116

[6] B. MEYER, M. STUBBE
EUROSTAG, a single tool for power system simulation
Transmission & Distribution International, March 1992