Operational effects of Voltage Management System considering Contingency

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Abstract—Recently, Korea has experienced voltage stability problem in metropolitan area. That was induced by a reactive power unbalance. So KEPRI (Korea Electric Power Research Institute) has decided to install the voltage control system for solving that problem and has started a new research project that is development of voltage management system.

Index Terms—Hierarchical Voltage Control, Slow Voltage Control, SVC, SVR, RTDS, and Voltage Stability.

I. INTRODUCTION

The voltage has a regional characteristic that is different from the frequency. Using this characteristic, research projects about the hierarchical voltage control system have been started in Europe for solving voltage and reactive power unbalance problems. It uses the regional characteristic of voltage and reactive power. It divides control areas by unique voltage characteristic and selects pilot bus of each control area. Then it maintains the pilot bus voltage by control generators.

And the slow voltage controller has been studied in North America. It must have load flow data of whole system. It calculates sensitivities between Buses and voltages. And it controls discrete devices (for example tap, capacitor, and reactor) for maintaining the system voltage.

KEPRI (Korea Electric Power Research Institute) proposes enhanced a voltage management system that is a coordinate voltage control system between the hierarchical voltage control system and the slow voltage control system. VMS consists of Master Controller, CVC (Continuous Voltage Controller) and DVC (Discrete Voltage Controller). CVC consists of main controller and several RPD ( Reactive Power Dispatcher). For establishing test-bed, we selected Cheju island system that has a unique voltage characteristic and is an independent system. We established test-bed using RTDS (Real Time Digital Simulator) that has HVDC. We also designed OXL, ULTC controller to simulate long-term voltage stability. CVC made of PI control block. It maintains the pilot bus voltage by control continuous reactive power sources (For example generator, FACTS and so on). DVC maintains the system voltage by control discrete devices. Load flow data come from SCADA/EMS, and it starts control when the pilot bus voltage is fluctuating. Master controller has two functions. First, it presents the pilot bus reference value through analyzing variety object functions those are the minimization of system loss, the improvement of reactive power margin, the improvement of voltage quality and so on. Second, it coordinates CVC and DVC. For example, master controller controls DVC like that switch on capacitors which magnitudes are the same as consumed reactive power by CVC. Then, CVC restores own reactive power margin. This paper’s the main issue is operation effects of VMS when power system experienced contingency.

II. HIERARCHICAL VOLTAGE CONTROL SYSTEM

It uses the regional characteristic of voltage and reactive power. It divides control areas by unique voltage characteristic and selects pilot bus of each control area. It maintains the pilot bus voltage by control generators. [1], [2] It is consisted of simple control blocks and uses simple data, so it’s too easy to install to real system and possible to control power system in real time. And we expect a quick recovery of system voltage and decreasing power loss of system and so on. But it has several defects. First, it’s difficult to install to complex system. Because characteristic between voltage and reactive power of complex power system for dividing control area and selecting pilot bus is not clear. So we can’t divide network and select bus easily. Second, until now, it can control just generator for improving system voltage. It doesn’t control discrete devices, it is an inefficient. Figure 1 is a concept of the hierarchical voltage control.

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III. SLOW VOLTAGE CONTROL SYSTEM

The study about the hierarchical voltage control has started from Europe. However the slow voltage control has started from North America. The former uses simple data, but the latter uses SCADA/EMS data and is based on numerical method.

It must have load flow data of whole system, so it connects with SCADA/EMS. It calculates sensitivities between bus voltage and reactive power to select control measures for improving system voltage. These measures include all of reactive power sources, for example generators, FACTS, Switched capacitor, series reactor, transformer tap and so on. Selected control signal transfer to each control device and control automatically using communication network of SCADA/EMS. [3] Through this progress, it controls several control devices at once for maintaining whole system voltage.

But it is not suitable real time control of power system because it must use a SCADA/EMS data. And it takes long time to calculate sensitivity between bus voltage and reactive power. So we don’t use SVC for improving short-term voltage stability.

IV. VOLTAGE MANAGEMENT SYSTEM

Recently, Korea has experienced voltage stability problem in metropolitan area. That was induced by a reactive power unbalance. So KEPRI (Korea Electric Power Research Institute) has decided to install the voltage control system for solving that problem and has started a new research project that is development of voltage management system. VMS is hybrid controller that is mixed the hierarchical control system and the slow voltage control system.

VMS consists of Master Controller, CVC (Continuous Voltage Controller) and DVC (Discrete Voltage Controller). CVC consists of main controller and several RPD (Reactive Power Dispatcher). CVC take a role of the hierarchical control system and DVC take a role of the slow voltage controller. Master controller is playing like a coordinator for optimal actions CVC and DVC.

A. Continuous Voltage Controller

The control scheme of CVC is similar to the hierarchical control system. Main controller of CVC orders RPD to output reactive power of generator using predetermined pilot bus data. RPD controls terminal voltage of each generator by this order. Figure 3 is a concept of CVC.

CVC made of PI control block. It maintains the pilot bus voltage by control continuous reactive power sources (For example generator, FACTS and so on).

B. Discrete Voltage Controller

The control scheme of DVC is similar to the slow voltage control system. DVC maintains the system voltage by control discrete devices. Load flow data come from SCADA/EMS, and it starts control when the pilot bus voltage is fluctuating. It decides what to improve voltage of system through the sensitivity analysis between voltage and reactive power. Compensation devices for improving voltage of power system...
are switched capacitor, series reactor, transformer tap and so on. DVC orders each control device to maintain voltage of power system using SCADA/EMS.

C. Master Controller

Master controller has two functions. First, it presents the pilot bus reference value through analyzing variety object functions those are the minimization of system loss, the improvement of reactive power margin, the improvement of voltage quality and so on. Second, it coordinates CVC and DVC. For example, master controller controls DVC like that switch on capacitors which magnitudes are the same as consumed reactive power by CVC. Then, CVC restores own reactive power margin. So system has always uniform reactive power margin. Especially almost this margin is consisted of continuous sources (for example generator, FACS etc.) those have a fast dynamics.

We called that system is VMS (Voltage Management System). Figure 6 is a concept of voltage management system.

![Fig. 6 Concept of Voltage management System](image)

D. Test-Bed for validating VMS

For establishing test-bed, we selected Cheju island system that has a unique voltage characteristic and is an independent system. We established test-bed using RTDS that has HVDC. We also designed OXL, ULTC controller to simulate long-term voltage stability.

Cheju island system has # buses and # generators. HVDC controller of test-bed has two control modes those are constant power, constant frequency, so we can select which one for simulation purpose. Figure 7 is a HVDC model of test-bed.

![Fig. 7 HVDC Model of test-bed system](image)

ULTC is very important to simulate long-term voltage stability. It is shown a characteristic of load recovery following time variation. Figure 8 is a ULTC model of test-bed.

![Fig. 8 ULTC Model of test-bed system](image)

Generator is a main measure to maintain system voltage. When a field current reaches to ceiling of OXL, reactive power output and terminal voltage of generator goes down. As a result, system voltages also go down. So we want an accurate simulation result then we must design OXL model. Figure 9 is OXL model of test-bed.

![Fig. 9 OXL Model of test-bed system](image)

V. SIMULATION RESULTS

For validating developed controller, we simulated several cases using test-bed. First is a changing operating value of pilot bus. Second is a fluctuating load level. We assume load variation situation that is the one of contingencies.

A. Changing Operating Value of Pilot bus

We verify a control action of developed VMS through changing operation value of pilot bus. If developed controller operates perfectly, then reactive power output of generator is changing following changing value of pilot bus for maintaining pilot bus voltage by changed operating value.

Figure 10 and figure 11 show a simulation result when operating value of pilot bus changes.

When operating value is changed from 1.02 to 1.03, system voltage is also changed from 1.02 to 1.03 by increased reactive power output of generator.
And when operating value is changed from 1.03 to 1.02, system voltage is also changed from 1.03 to 1.02 by decreased reactive power output of generator.

### B. Fluctuating Load Level

Next we simulated a load variation case. We assumed that load variation is a contingency of power system. So we made a simulation case using bar switch of RTDS. If you want to increase load level of whole system, then you change load bar to upper. If you want to decrease load level of whole system, then you change load bar to lower.

Figure 11 shows control effects of CVC when load variation. The blue line is a simulation result without CVC and the red line is a simulation result with CVC. We can see control effects of CVC. See the red line. When load is increased, the red line falls down immediately, and it climbs slowly because CVC controls generators to maintain pilot bus voltage. However, the blue line is un-change after load variation because CVC didn’t connect with system and generators were not controlled.

We can know more information about VMS control action through figure 13. The red is operating value of pilot bus, the green is real value of pilot bus, the violet is reactive power margin of whole system and the yellow is reactive power output of regulated generator. When load is increased, reactive power output increase and reactive power margin of whole system decrease for maintaining pilot bus voltage.

### VI. CONCLUSION

KEPRI decide to develop new hybrid control system for solving voltage stability problem of metropolitan area in Korea. This paper introduces developed VMS (Voltage management system) and shows operation effects of this controller considering contingency. Although we consider only load variation case to analysis contingency, we think that it is enough to show control effects in uncertainty of power system.

In the future we will make new scenarios for validating developed controller, for example generator trip case, line trip case, HVDC trip case and voltage collapse case. And we will verify technical and economic operation effects of developed controller.

### VII. REFERENCES


VIII. BIOGRAPHIES

**Su-Chul Nam** received his B.S and M.S degree in Electrical Engineering from Korea University, Korea in 2001 and 2006 respectively. He has extensive experience with transient and dynamic stability. He has performed and directed load flow, short circuit, railroad electrical system, and protective relaying studies. Mr. Nam joined KEPRI’s Power System Analysis Center as a researcher in Feb 2006 where he is developing an integrated optimization scheme for reactive power management system for KEPCO and also participating in several transmission power system studies.

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