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Application of Intelligent Voltage Control System to Korean Power Systems

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Abstract

The Korea power system has been operated more closely to stability limits in state heavy-load because of growth in load-demand and the reactive power loss have been increased due to the installation of long-distance transmission lines, since the power plants are located far from load-demand regions. The voltage collapse can be caused by reactive power unbalance. Some advanced countries experienced massive blackout due to voltage collapse. In order to solve voltage problems, several advanced countries are operating voltage and reactive power control system by taking into account the inherent characteristic of their individual power system. Recently, secondary control system and intelligent control system for Jeju power system have been reported in Korea. But voltage control system about mainland power system has not been reported. This paper presents the applicability of intelligent voltage control system for Korean power systems.

Keywords: Intelligent voltage control system, Sensitive matrix, Expert system

INTRODUCTION

Recently, massive power outages in Europe and North America were caused by unbalances in reactive power, resulting in voltage collapse. In order to solve reactive power unbalance problem several advanced countries are operating the voltage and reactive power control system by taking into account inherent characteristic of their own power system[1,2]. The Korea power system has been operated more closely to stability limits because of rapid growth in load-demand. And reactive power losses are increased due to the installation of long-distance transmission lines since the generation power plant are located far from the load-demand regions. For this reason, there is reactive power demand continues to increase. However, the power system voltage is maintained only by engineering knowledge and judgment of the operators since it is not actually easy to secure the site for voltage compensation equipment and the regional systematic voltage control system is not really prepared. Newly, the KEPCO recognized the need for automation of the voltage control and developed intelligent voltage control system and secondary voltage control system[3,4].

The methodology of the voltage control may be classified into a numerical optimization method and intelligent control. In case of intelligent voltage control system it has been developed real-time voltage and reactive control expert system using sensitivity tree in Canada in the 1980s[5]. Spain developed SEGRE[6] and SETRE[7,8] in the 1990s and they has been successfully operating in domestic power system. They are basically hybrid system using intelligent method and sensitivity tree-based numerical computation. But they are not easy to develop since numerical module and search method are not reported as well as operation method of system and structure of power system is various.

The intelligent voltage control system performs voltage control using sensitivity matrix of generator terminal voltage, parallel capacitor/reactor, and transformer Tap. It can adjust abnormal voltage range and target voltage range and can use basic power system data such as PSS/E data. Generally, effective searching method is the most important factor to improve performance of expert system since the process of obtaining a solution in intelligent system has to search the state space with inference of target. This paper uses existing weighted evaluation function and least-cost search method. And a continuous quantity such as generator terminal voltage converted to discrete quantity through the quantization process in order to accurate voltage control.

The error range in the sensitivity matrix must be precise because the sensitivity matrix uses linearization model for nonlinear system. The error of intelligent voltage control system in a performance test in Jeju power system was precise, up to a maximum of 1%. But the error range in the sensitivity matrix has to be verified in order to test applicability of the intelligent voltage control system for a mainland power system, relatively large power system than Jeju power system. This paper presents an artificial intelligence based voltage control system to adjust the bus voltage of the power system to within the specified range.

STRUCTURE OF INTELLIGENT VOLTAGE CONTROL SYSTEM

The structure of intelligent voltage control system to be explored in this paper is described in Fig. 1, where the intelligent controller is made up of the sensitivity matrix based numerical module and the knowledge base including a wide variety of information related with power system status and control knowledge.

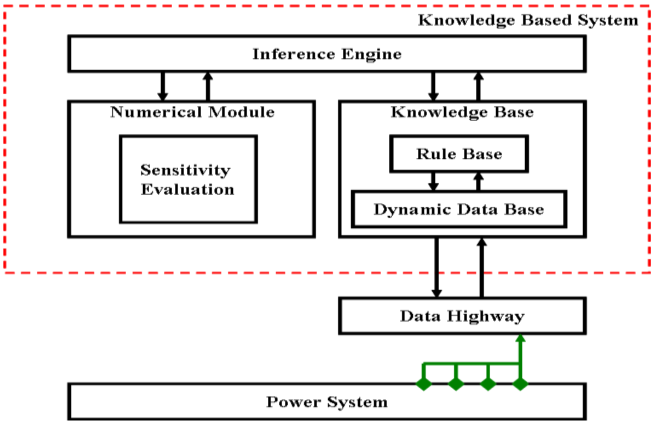

Figure 1: Structure of intelligent voltage control system

Knowledge Base

The knowledge in a specific problem domain is classified by truth and rule and then stored in the database and rule base, respectively. Database and rule base are in the following:

◎Database

- Upper and lower limit of each bus voltage

- Upper and lower limit of the voltage regulation

- Upper and lower limit quantity of compensation devices

- Priority of compensation devices

- Quantization level of generator terminal voltage

◎Rule base

- If the voltage exceed upper and lower limit of each bus voltage the system operate the controller

- If abnormal voltage occurred, firstly the controller constitute sensitivity tree

- The controller selects the compensation device of largest sensitivity

- If selected reactive power compensation device's capacity is lack, the controller selects the second highest compensation device

- The controller operates the specified priority of compensation devices

- If abnormal voltage occurred in several bus, the controller operate based on the greatest abnormal bus voltage

- If bus voltage don't adjust within voltage regulation by using compensation device of first ranking, compensation device of next ranking is committed

- Reactive power compensation amount determine Linear Prediction method

Numerical Module

Assuming an N bus power system with M control actions, the relationship between the bus voltages and the control actions can be represented as shown in Fig. 2.

It is pointed out that the changes in each control action have significant impacts on the voltage in some buses. For a particular voltage violation, it is possible to compute the control action needed to remove this voltage violation by the sensitivity technique. It is worthy to mention that the control action should neither exceed the specified limits nor incur new voltage violations of other buses. The sensitivity matrix is a fundamental parameter in the intelligent voltage control system. By defining the relationship of changes in bus voltages according to compensation changes in the generator terminal voltage, shunt capacitor/reactor, and transformer tap, it selects the control actions when the voltage violation occurs and determines the quantity of compensation requirement.

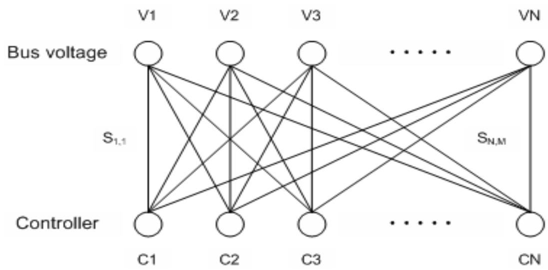

Figure 2: Description of bus voltage and control actions

The sensitivity matrix is reestablished by the relationship between the voltages and the reactive power in the Jacobian matrix constructed from the load flow equation.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \vdots & \frac{\partial P}{\partial V} \\ \cdots & \cdots & \cdots \\ \frac{\partial Q}{\partial \delta} & \vdots & \frac{\partial Q}{\partial V} \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \quad (1)$$

Assuming that the voltage angle is negligible in the relation with the reactive power, the relationship between the voltage and the reactive power is encapsulated in (2).

$$[\Delta Q] = \left[\frac{\partial Q}{\partial V}\right][\Delta V] \quad (2)$$

$$[\Delta V] = \left[\frac{\partial Q}{\partial V}\right]^{-1}[\Delta Q] \quad (3)$$

$[\partial Q / \partial V]$ is the Jacobian matrix of load flow calculation in (2).

That is, $[\partial Q/\partial V]^{-1}$ is the inverse matrix of $[\partial Q/\partial V]$ and called the sensitivity matrix which estimates the changes of bus voltages against the changes of reactive power. The sensitivity matrix is given by the control actions as shown in (4).

$$\begin{aligned}\Delta V_i &= S_{Vg}\cdot U_{Vg}\\ \Delta V_i &= S_{sh}\cdot U_{sh}\\ \Delta V_i &= S_{Tap}\cdot U_{Tap}\end{aligned} \tag{4}$$

STATE-SPACE MODEL OF INTELLIGENT VOLTAGE CONTROL SYSTEM

After a given problem define the representation model, to solve the problem we need a several strategy and one of the key strategies is search. The searches will be defined by the trial process to assess possible solution paths and reach from initial state to final state. It may be divided into two categories: blind searches and heuristic searches. The blind searches divided to breadth-first search and depth-first search. But, this method is not good in case that state-space is large due to it do not contain intelligent decision. The heuristic searches is a method to continuously search a solution after getting rid of the solution path that seems inappropriate by judgment such as heuristic knowledge or cost function. This method could reduce state-space but might be occurred that do not solve. This paper uses state-space model as shown in Fig. 3.

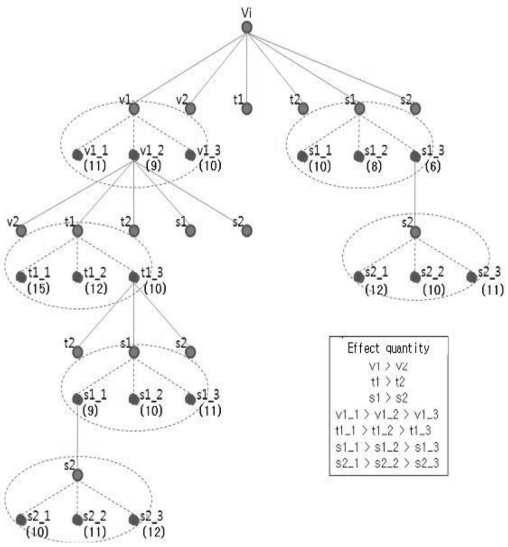

Figure 3: State-space model of voltage control

Least-cost search

This paper used least-cost search to minimize weighted evaluation function such as expression (5).

$$\min(\lambda V_{vio} + \sum \alpha|\Delta V_{gi}| + \sum \beta|\Delta T_k| + \sum \gamma|\Delta Q_i|) \tag{5}$$
$$[\lambda >> \gamma >> \beta >> \alpha]$$

V_{vio} is newly occurred abnormal bus voltage in normal bus.

The search process following:

•Step 1:

About the bus where the abnormal bus voltage, a v1 node that the largest effect quantity (sensitivity value × control quantity) was selected by the system. And the system expands v1 node as three quantized effect quantity. Using three quantized effect quantity, the system calculated liner prediction and weighted evaluation function about all the bus voltage. Evaluation function quantities of expanded node are 11,9,10 as seen figure 2. The system selected v1_2 node that the smallest of evaluation function value and progress a selection of compensation device of step 2.

•Step 2:

The system performs liner prediction by using effect quantity of v2. As a result, the system selected transformer tap t1 because abnormal bus voltage occurred in normal bus. And through the same process of v1 node, the system selected t1_3 node that the smallest of evaluation function quantity. Finally, if abnormal bus voltage is dissolved, the system selected compensation device of step 3. Conversely, if abnormal bus voltage is solved, the system finished the search process.

Case Study

Generally, the voltage in power system fluctuates due to the constantly changing load even if no accident occurs. Therefore, the power system must be operated within the specified voltage range for voltage stability and facility protection. In the Korean power system, the bus voltage range of the transmission system is defined as follows.

$$0.95 < \text{bus Voltage} < 1.05 \tag{6}$$

In this paper, the operating conditions of the developed voltage control system are set as follows.

① Upper and lower limit of abnormal bus voltage

: 0.95 < V or V > 1.05

② Upper and lower limit of the voltage regulation

: 0.97 < V or V > 1.03

③ Upper and lower limits of generator terminal voltage [p.u.]

: 0.95 ≤ generator terminal voltage ≤ 1.05

④ Priority of compensation devices

: Generator >shunt capacitor> transformer tap

⑤Quantization level of generator terminal voltage : 5[step]

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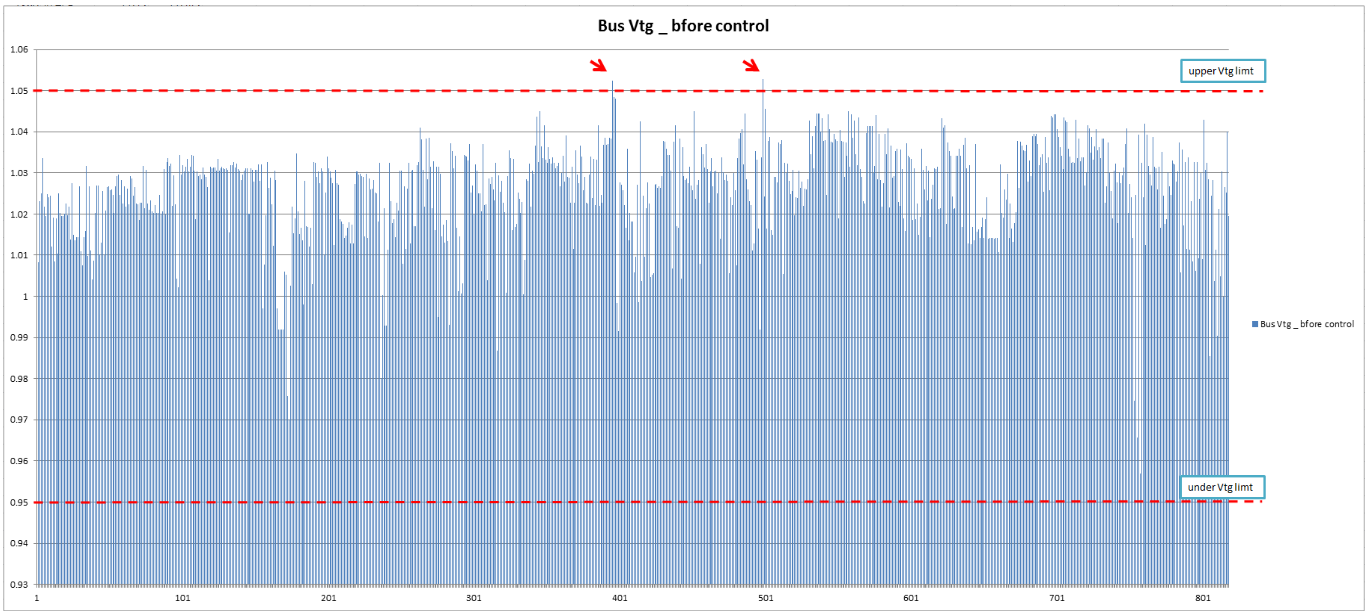

Figure 4: Bus voltage profile at steady state

Fig 4 shows the power system bus voltage profile at steady state. Looking at Fig 4, two bus voltages exceeded the voltage range. Fig 5 and 6 show the voltage profiles before and after voltage control for voltage violation bus voltage. After the voltage control operation, it can be confirmed that all the bus voltage is adjusted within the specified voltage.

CONCLUSION

This paper presents an artificial intelligence based voltage control system to adjust the bus voltage of the power system to within the specified range. The developed voltage control system showed satisfactory performance as a result of voltage control. In future, various cases will be developed to verify the performance of the intelligent voltage control system.

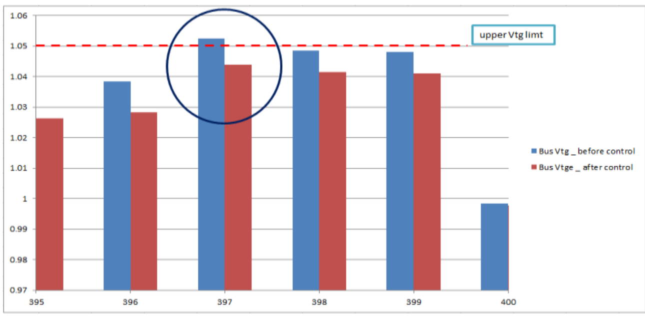

Figure 5: Voltage profiles before and after voltage control

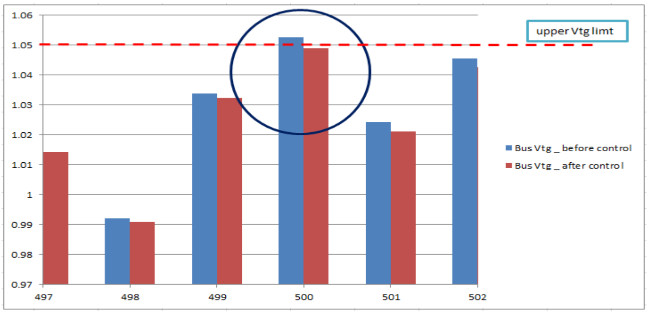

Figure 6: Voltage profiles before and after voltage control

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