# An Intelligent Voltage Control System for Large scale Power System

WONKUN YU[1], HEUNGJAE LEE AND[2] KYEONGSEOB LEE[3]
Department of Electrical Engineering[1,2,3]
Seoil University[1], Kwangwoon University[2], Shinsung University[3]
28 Yongmasan-ro 90-gil, Jungnang-gu, Seoul[1], 20 Gwangun-ro, Nowon-gu, Seoul[2],
1 Daehak-ro, Jeongmi-myeon, Dangjin-si, Chungcheongnam-do[3]
KOREA
ywk@kw.ac.kr[1], hjlee@kw.ac.kr[2], kyeong@shinsung.ac.kr[3]

*Abstract:* - In many developed countries, voltage and reactive power control system suitable for the domestic power system is operated in order to secure the voltage stability depending on the reactive power. Recently, Korea power system has been operated more closely to stability limits in state heavy-load because of growth in load-demand and 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. For this reason, intelligent voltage control system has been proposed to maintain voltage stability in Jeju power system, Korea. This paper presents the application of the developed intelligent voltage control system to the Korean power system with dense structure and check up on various issues that needs to be applied to large scale power systems.

*Key-Words: - Expert system, Sensitivity, Reactive power, Intelligent voltage control system*

## 1 Introduction

The large scale black-out in Europe and the North America was caused by voltage collapse due to reactive power imbalance[1-3]. To avoid this problem, several advanced countries have developed a voltage control system to maintain voltage stability[4,5]. A methodology of the voltage control may be divided a numerical method using optimization 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[8]. Spain developed SEGRE[9] and SETRE[10,11] 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 various structure of power system.

The Korea power system has been operated more closely to stability limits in state heavy-load because of growth in load-demand and 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. For this reason, an intelligent voltage control system for maintaining voltage stability has been proposed in Korea. The proposed system is a hybrid system based on expert system and sensitivity tree, and performance test of intelligent voltage control system in Jeju island power system obtained satisfactory result[6,7].

Recently, interest in micro grids and DC grids has increased as the capacity of various renewable energy sources has increased, and papers have been reported on voltage control in these systems[12-13]. They have a non-dense distributed structure. However, as shown in Figure 1, Korean power system has a very dense power system structure. Therefore, it is difficult to have a small scale distributed power system structure based on the renewable energy source, so a voltage control system capable of managing the voltage of the entire system is needed.

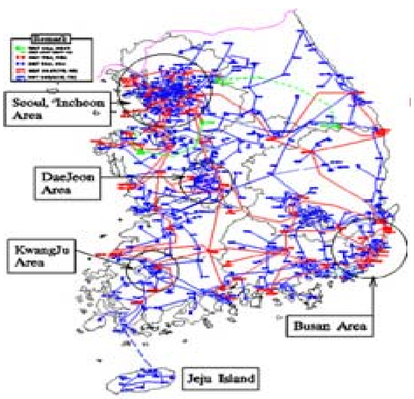


**Fig. 1,** Power system in Korea

This paper presents the application of the developed intelligent voltage control system to the Korean Power System with dense structure and check up on various issues that needs to be applied to large scale power systems.

## 2 Structure of Intelligent Voltage Control System

The structure of intelligent voltage control system to be explored in this paper is described in Fig. 2, 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.

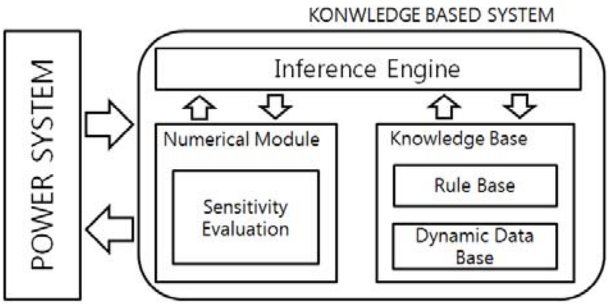


**Fig. 2,** Structure of intelligent voltage control system

### 2.1 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:

#### 2.1.1 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

#### 2.1.2 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

### 2.2 Numerical Module

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.

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

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).

$$[\Delta Q] = \left[\frac{\partial Q}{\partial V}\right][\Delta V] \tag{2}$$

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

$[\partial Q / \partial V]$ 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).

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

### 2.3 Inference Engine
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.

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

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

$V_{vio}$ 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 3. 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.

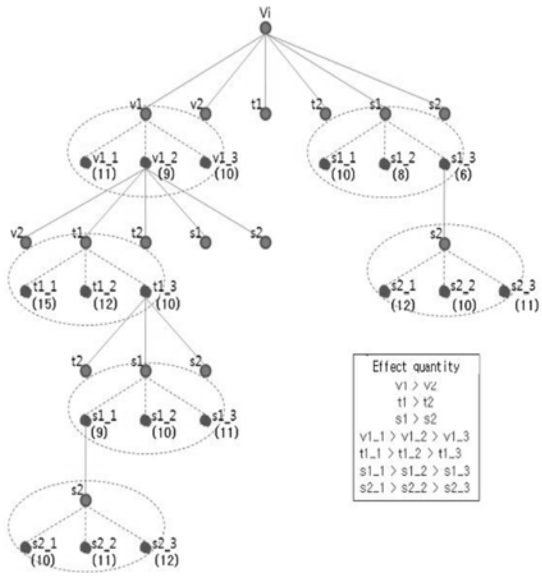

**Fig. 3,** State-space model of voltage control

## 3 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.

$$0.95 < \text{bus Voltage} < 1.05 \quad (6)$$

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

- Upper and lower limit of abnormal bus voltage
  : 0.95 < V or V > 1.05
- Upper and lower limit of the voltage regulation
  : 0.95 < V < 1.05
- Upper and lower limits of generator terminal voltage [p.u.]
  : 0.95 ≤ generator terminal voltage ≤ 1.05
- Priority of compensation devices
  : Generator >shunt capacitor> transformer tap
- Quantization level of generator terminal voltage
  : 3

Fig 4 shows all bus voltage profile. Looking at Fig 3, several 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.

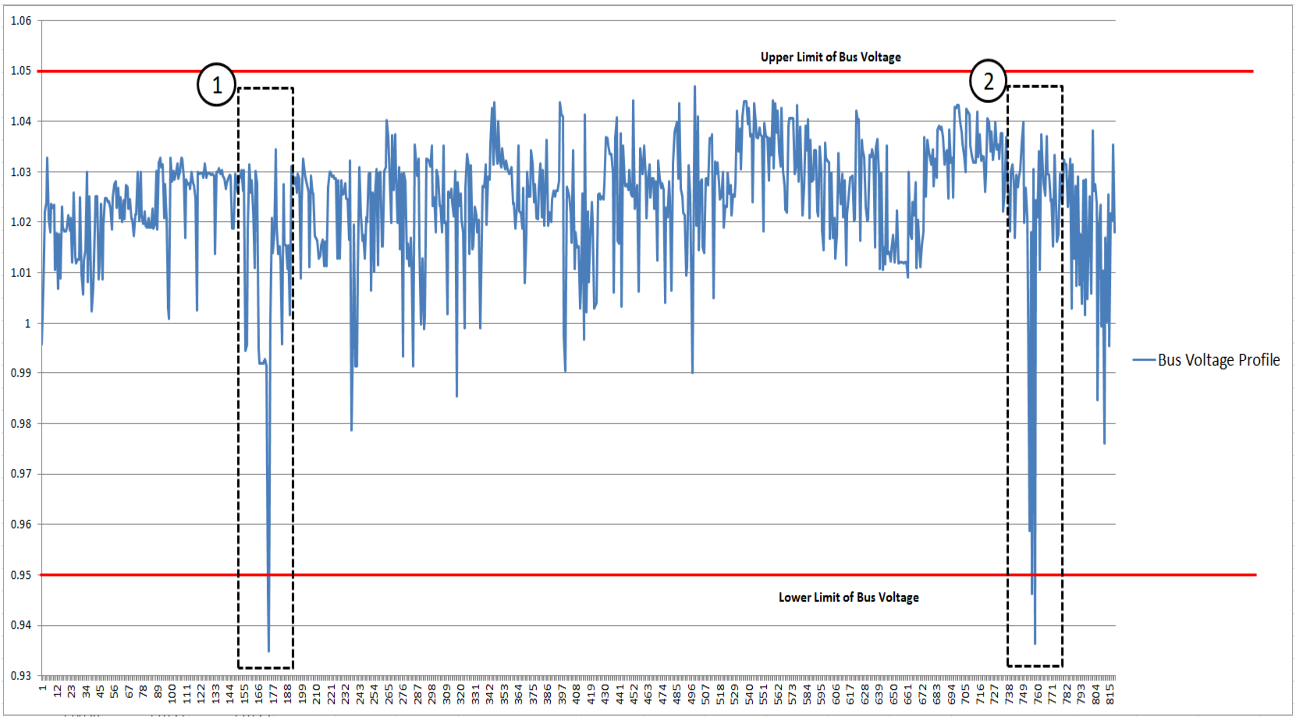


**Fig. 4,** All bus voltage profile

Table 1. Voltage[pu] profile in area 1, 2

| Bus No. | No Control | 1st Control | 2nd Control |
|---|---|---|---|
| 3380 | 0.94613 | 0.96467 | 0.96472 |
| 3390 | 0.93494 | 0.95374 | 0.95380 |
| 10180 | 0.94618 | 0.94680 | 0.96432 |
| 10190 | 0.93644 | 0.93707 | 0.95477 |

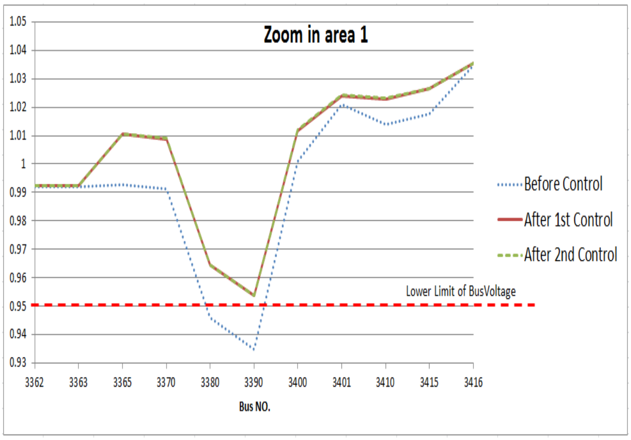


**Fig. 5,** Voltage profile in area 1

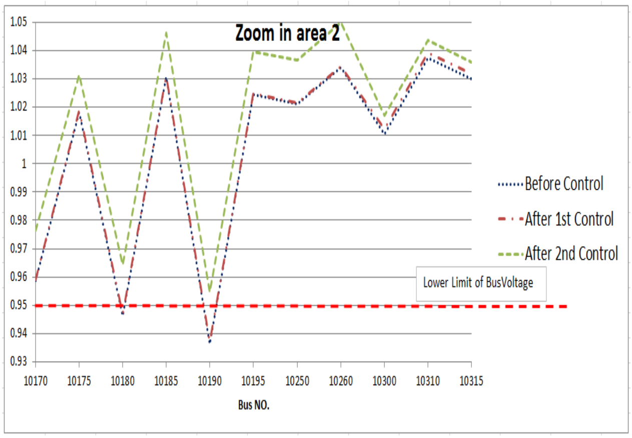


**Fig. 6,** Voltage profile in area 2

## 4 Conclusion

This paper examined the performance of intelligent voltage control system by applying it to mainland power system in Korea. Because of the Jeju power system is a small single system all the control devices in the power system can affect the abnormal bus voltage. Therefore, it was possible to manage several bus voltages when the control equipment was operated based on the bus voltage in which the abnormal bus voltage was greatest. However, in a large-scale power system, when more than two abnormal bus voltages are occurred, as a result of controlling the bus with the largest abnormal bus voltage, the abnormal bus voltages were solved by controlling several times. In the future, intelligent voltage control system will be suitable system for large scale power system by applying various techniques to solve these problems.

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