Design of SPS in the Korean Power System Against Faults on 765 KV Lines

Jong-Young Park†, Jong-Keun Park* and Byung-Tae Jang**

Abstract - In Korea, the protection systems against the instability of the nation's power system are insufficient in contrast with many other countries. In addition, there have just been studies carried out on detecting power system instability, while only a few studies pertaining to protection plans against instability exist. This paper focuses on systems to protect against the instability phenomena in the Korean power system. In this paper, we survey possible contingencies in the Korean power system and suggest outline and specs of the SPS (System Protection Scheme) against faults on the 765 kV line, based on simulations. It is concluded that event-based SPS for transient stability is appropriate for the Korean power system. In the simulations, the most severe contingency on the Korean power system is the fault on 765 kV transmission lines. If one of these lines is tripped by a fault, synchronism may be lost on the power plants near this line because of heavy power flow carried by them. In addition, undervoltage in the Metropolitan region is a serious problem in this case since this region receives about half its total power flow through these lines. In order to prevent a synchronism loss, some power plants have to be rejected according to the situations in the simulations.

Keywords: event-based, Korean power system, SPS (System Protection Scheme), transient stability

1. Introduction

In recent years, there has been a significant growth in complexities and scales of the electric power system in Korea. Because of the complexity of electric power systems, rapid load increases or severe faults, protections and emergency controls against instability on power systems are important. In many countries, protection systems against various instability phenomena have been installed on the power system and operated adequately to their own characteristics. However, in Korea, the protection systems that have been implemented to prevent instability in the power system are insufficient. There have only been studies on detections instability on power systems [1, 2], and few studies on protection plans against instability exist.

A CIGRE Task Force Report [3] has specified the function of system protection schemes (SPS) and their various types. This paper describes the general matters of SPS and the characteristics of the Korean power systems. Then this paper finds a type of SPS adjusted to the Korean power system based on the simulations.

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2. Theoretical Review for SPS

A CIGRE report [3] identified the function of SPS as detecting abnormal system conditions and taking predetermined, corrective action (other than the isolation of faulted elements) to preserve system integrity and provide acceptable system performance. SPS's are designed to meet the requirements of power systems in which they are installed, so SPS's have various appearances according to the instability phenomena that they are charged with. Fig. 1 [3] illustrates the general structure of a SPS.

SPS's are classified by their input variables into response-based SPS and event-based SPS. Response-based SPS's use electric variables (voltage, frequency, etc.) and initiate non-continuous stabilizing actions after measuring disturbance. This type of SPS acts so slowly that it can only be used if the power system has sufficient time before becoming unstable. In order to shorten response time, the SPS may use a particular algorithm, which makes it difficult for an operator to understand the actions of the SPS.

Event-based SPS's are designed for operation only upon the recognition of a particular combination of events and are thus based on the direct detection of the event (e.g. the loss of several lines in a station). Pre-planned target actions could be local or remote. They commonly act very quickly, making them effective when rapid control actions are required. The rules are generally developed from off-line simulations, but some of these SPS's develop rules from on-line simulations automatically and periodically.

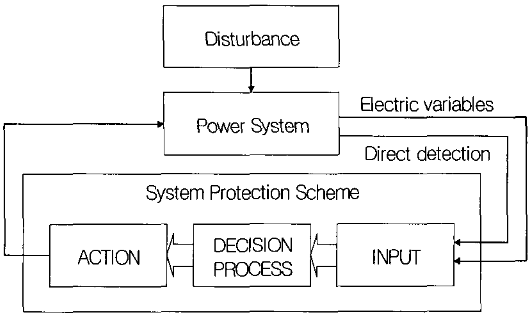

Fig. 1 General structure of an SPS [3]

In addition, SPS's are classified into central control type and local control type by the range in which they receive input signals. Central control type SPS's receive the input signal from each terminal unit, and the central control unit determines whether to act or not. If control actions are required, the central control unit sends signals to terminal units, and then control actions are actuated. Local control type SPS's use signals only from nearby points to determine whether to act or not.

Central control type SPS's are usually concerned with instability phenomena in a wide ranging area, but local control type SPS's are concerned with instability phenomena in a relatively small area. However, some local control type SPS's cover a wide area according to their operation algorithms. Central control type SPS's are comprised of a central control unit that decides control action, and terminal units that measure variables or execute control actions and communication systems among the units. So these SPS's have high cost, but can manage even more severe and wider instability.

Because SPS's consist of various types as mentioned above, it is very important when installing the SPS to understand the characteristics of the related electric power system.

3. Review of the Korean Power System

South Korea ranges north and south and its power demand is increased continuously because of industrial developments. Most large demands are in the metropolitan region located in the northern part, and most large capacity generations are located in the southern part and along the coastal regions. Due to these geographical features, there are large amounts of power flowing from south to north in the Korean power system. Therefore, some transmission lines adjacent to the Metropolitan region play an important role in the power flow transmission in Korea. As a result, the faults on these major transmission lines may incur a severe instability on the power system. Fig. 2 shows the power generation and loads in the Korean power system and the structure of the main transmission lines, which are the 345kV and 765kV lines.

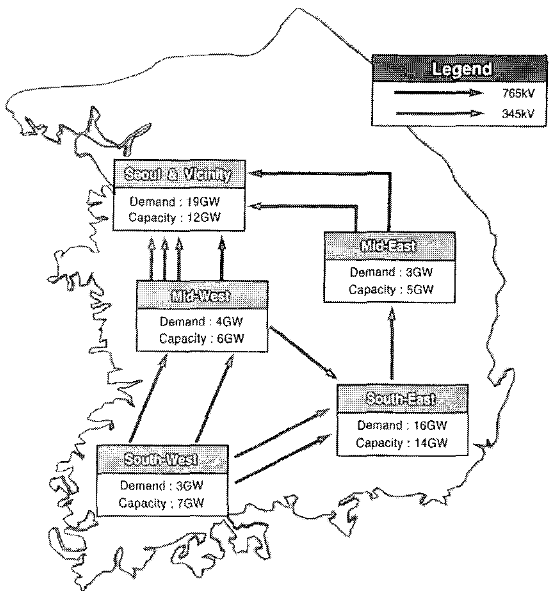

Fig. 2 Power generation and load in the Korean power system

One possible instability phenomenon related with faults on these lines is the loss of synchronism. If one of the main transmission lines is cut off by accident, the power flow from generators is limited by a shortage of transmission capacity, causing some generators to become out of step. The other is undervoltage in the capital region. Though a synchronism loss does not occur, the generation in the metropolitan region becomes insufficient due to the decrease of power flowing through that line, resulting in undervoltage. This may bring about a system collapse through successive actions of under-voltage relays.

In Korea, there are plenty of transmission lines compared with other countries, so all faults on insignificant transmission lines do not cause serious instability in the power system. However, faults on 765 kV lines can bring about instability as stated above. In these cases, wide area controls are required to prevent power system collapse. This paper investigates the results of these faults and proposes a SPS to prevent power system collapse.

4. Design and Case Study

4.1 Structure of SPS

Because faults on 765 kV lines affect the Korean power system over a widespread area, it is required to measure and analyze information from a broad region in order to prevent instability on power systems by those faults. In addition, stabilizing actions that make economic loss, e.g. load shedding and generator rejection, can be minimized by exact measurement. In session 3, synchronism loss and undervoltage problems are the most probable instability phenomena to occur in the Korean power system. To satisfy transient stability requirements, the SPS should operate so rapidly that an event-based SPS is appropriate to the Korean power system. Central control type SPS is also suitable for more efficient stabilizing actions.

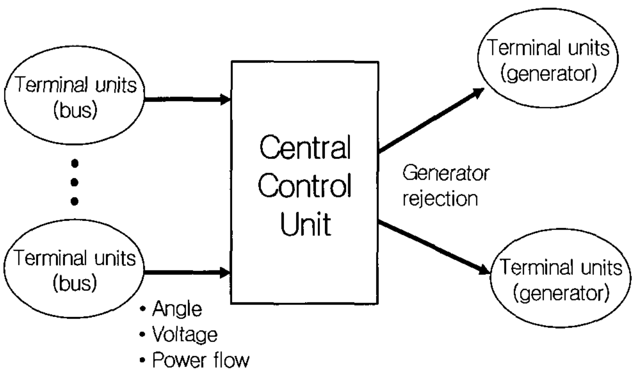

Fig. 3 Structure of the proposed SPS

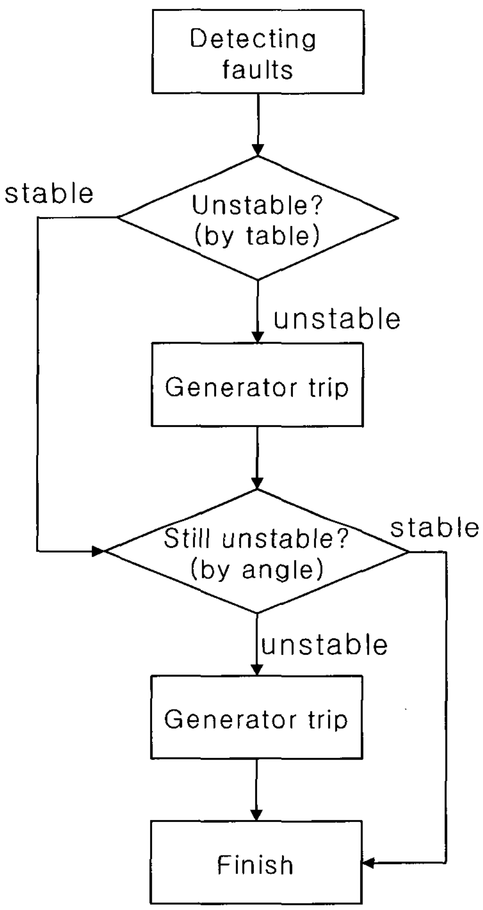

Fig. 4 Flow chart of operation

Fig. 3 presents the block diagram of the structure of the proposed SPS. Terminal units at selected buses transmit measurements e.g. angle, voltage and amount of power through communication systems. Then the central control unit determines whether to act or not. Decision logic on the part of the central control unit consists of two parts. One (primary) is based on detection of line tripping and the other (secondary) is based on detection of angle difference between both ends of the line. The secondary logic is a backup of the primary logic to improve the security.

Fig. 4 depicts the operation flow chart. When a terminal unit detects the fault, the stability is estimated by measuring power flows on objective lines and comparing them with those of the operation rules tables. And then, the difference between both ends of the transmission line is detected to conclude whether the system is stabilized or not If the power system is still unstable, the secondary logic is activated to stabilize the system by tripping generators.

4.2 Determination of Operation Rules

The amount of generation rejection in the operation rules table can be calculated by Equal Area Criteria (EAC) [4]. In this method, each generator group (generator groups 1 & 2) is modeled as a single equivalent generator. The P-δ curve of the equivalent generator is formulated as (1), in [5].

$$P(\delta,t) = a\sin\delta(t) + b\cos\delta(t) + c \tag{1}$$

In this description, $P(\delta,t)$ is active power generation and δ is the phase angle of a generator. The coefficients, a, b and c are calculated by the curve fitting method. From simulation with PSS/E, we obtain the data of $P(\delta,t)$ and $\delta(t)$ From (1), we get

$$\mathbf{P} = \mathbf{A}(\boldsymbol{\delta})\mathbf{x} \tag{2}$$

where

$$\mathbf{P} = [P_1 \ P_2 \cdots P_n]^T$$

$$\mathbf{A}(\boldsymbol{\delta}) = \begin{bmatrix} \sin\delta_1 & \cos\delta_1 & 1 \\ \sin\delta_2 & \cos\delta_2 & 1 \\ & \vdots & \\ \sin\delta_n & \cos\delta_n & 1 \end{bmatrix}$$

$$\mathbf{x} = [a \ b \ c]^T$$

P_i, δ_i : active power and phase angle at i-th sampling time

Using curve fitting method,

$$\mathbf{x} = \left(\mathbf{A}^T\mathbf{A}\right)^{-1}\mathbf{A}^T\mathbf{P} \tag{3}$$

By the above procedure, the P-δ curve used to calculate the amount of generation rejection in the operation rules table can be obtained.

Fig. 5 shows the objective 765 kV lines and the generator groups related with those lines in the Korean power system (Fig. 2). As we mentioned above, these two 765kV lines are selected because the faults on these lines have effects on the stability of the Korean power system to such an extent that certain stabilizing actions must be executed.

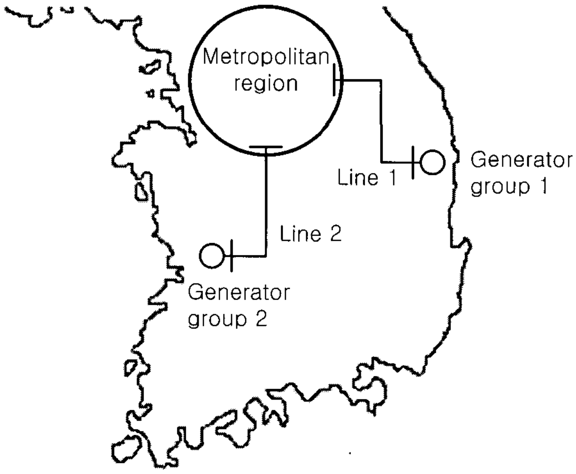

Fig. 5 Objective 765 kV lines and generator groups

Fig. 6 shows the P-δ curve of the Generator group 2 when Line 1 is tripped. If Line 1 is tripped due to a fault occurrence, power generation is limited as shown on the P-δ curve (Fig. 6). As such, the synchronism of the power system is lost in such a case, unless mechanical input power P_M is reduced by generator rejection.

An amount of generation rejection is also calculated by EAC. It is desirable to reject generation as much as possible to reduce the impact on the power system and to curtail the recovery costs.

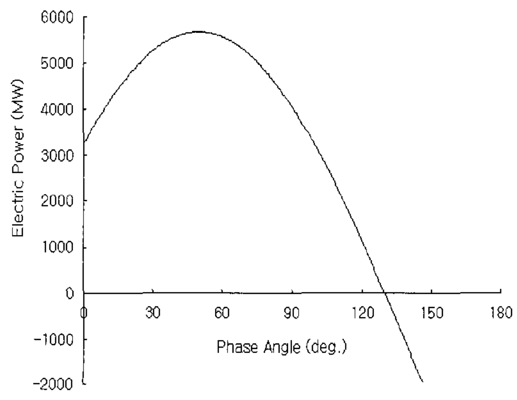

Fig. 6 P-δ curve of Generator group 2 when Line 1 is tripped

In Fig. 6, the largest amount of power that can be transferred is 5668.2 MW (6020.8MW before line tripping) so that, at least, a generation of 352.6MW must be rejected to maintain the synchronism of the power system based on EAC. From this result, we know that more than one generator of Generator group 1 must be rejected, where the power generation of one generator is from 980 MW to 1045 MW in the peak load case. Because there is no consideration of the kinetic energy given to the generator in the above analysis, the simulation must be done for each case to complete the operation rules of the SPS.

Using the same method, the simulation is executed for each case. In the simulation, there is no need to reject the generation when Line 2 is tripped. However, the countermeasure is required for that case because the power flow may be instantaneously increased more than in the simulation. For that purpose, the angle difference between both ends of the line can be used as the index to determine whether the system is stable of not. If the difference goes beyond the limited value, some stabilizing action must be executed.

This paper proposes rules as in Table 1 based on the investigation by the above simulations. The SPS is designed for dealing with faults on 765 kV transmission lines (Line 1, Line 2). Load shedding for voltage maintenance is supposed to be executed by undervoltage load shedding (UVLS) independent of the proposed SPS.

It is assumed that generator groups can be rejected within 750 milliseconds after the terminal unit detects an excess of angle deference between both ends of the line. To implement this logic, the following units are needed.

- Terminal units (bus): both ends of line 1 and line 2
- Terminal units (for generator tripping): generator group 1 and group 2

Table 1 Operation rules of proposed SPS

Faults		Primary action	Secondary action
Line 1 tripped	Flow over 2,500 MW	Rejecting two generators in group 1	Generator group 1 is completely rejected when the angle difference becomes over 60°
	Flow under 2,500 MW	Rejecting one generator in group 1	
	Flow under 2,200 MW	No generator rejection	
Line 2 tripped		No generator rejection	Generator group 2 is completely rejected when the angle difference become over 60°

To verify the proposed SPS in the Korean power system, 2005 data have been used, and the next three cases underwent examination. Case 1 is a peak load condition, and case 2 and case 3 are 10% and 30% off-peak conditions, respectively. Table 2 represents conditions of each case and amount of power flow on 765 kV transmission lines. In each case, faults on line 1 and line 2 are simulated. All faults are 3 phase ground faults, followed by line tripping. Each case is simulated by PSS/E.

Table 2 Overview of each case and amount of power flow on 765 kV lines in simulations

Transmission line	Line 1	Line 2
Case 1: peak load	2998.6 MW	2603.4 MW
Case 2: off-peak (10%)	2324.2 MW	2086.0 MW
Case 3: off-peak (30%)	2104.4 MW	1840.8 MW

Fig. 7 is part of the simulation results of Case 1. In this simulation, line 1 is tripped because of a fault. Fig. 7 shows that two generators should be rejected in that case. On the condition of Fig. 8, it is assumed that the primary rule of SPS does not work for some reason, so the secondary rule is activated. By this secondary control action, a synchronism is maintained. In a normal condition, primary rules play indispensable roles in preventing loss of synchronism due to faults on 765 kV transmission lines. Secondary rules are useful when primary rules fail in their roles due to unexpected reasons.

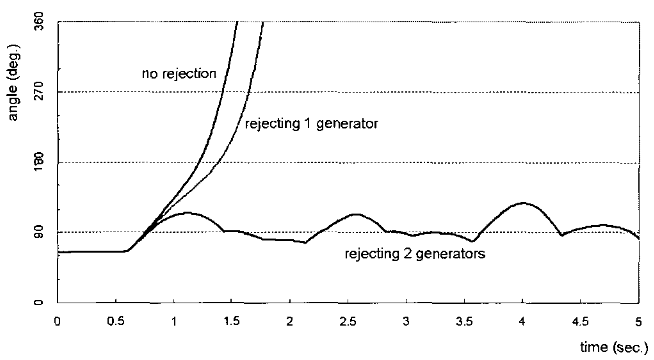

Fig. 7 Angle spread between both ends of line 1 (Case 1): w/o control action and w/ primary control action

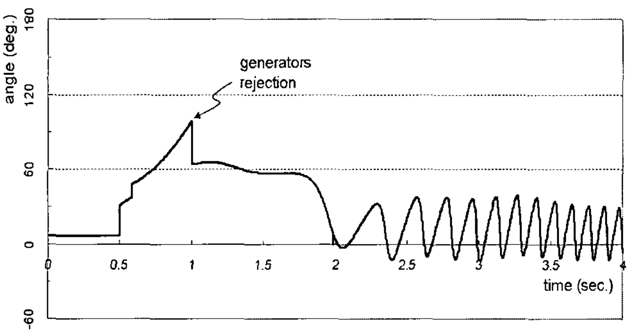

Fig. 8 Angle spread between both ends of line 1 (Case 1): w/ secondary control action

Table 3 presents an overview of simulation results. With 2005 data, trip of line 2 does not cause a loss of synchronism, and trip of line 1 does cause a loss of synchronism according to the amount of power flowing through the transmission lines. However, the operating condition in the power system is in for some changes according to the increase of power demand or by other reasons, which emphasizes the importance of the dual logic

Table 3 Overview of simulation results

	Line 1 tripping		Line 2 tripping
Case1	Unstable	Stabilized by primary action: rejecting 2 generators ※	Stable
Case2	Unstable	Stabilized by primary action: rejecting 1 generator	Stable
Case3	Stable		Stable

※ The secondary algorithm is tested in this case on the assumption that the primary algorithm does not work for some reason. Fig. 8 shows that the system is stabilized.

5. Conclusion

This paper attempts to define and describe general features of the SPS, and also applies SPS to the Korean power system. In Korea, the most possible serious instability phenomena are the loss of synchronism and undervoltage in the metropolitan region due particularly to faults on 765 kV transmission lines. To maintain stability of the power system against these serious faults, controls in a broad area are necessary. With the SPS, the power system can maintain transient stability and then keep the proper voltage profile by undervoltage load shedding.

Because rapid actions are required, the event-based SPS is suitable for the Korean power system and the central control type is also appropriate for more efficient stabilizing actions against serious faults. Terminal units located at selected spots measure electric variables and send signals to the central control unit. If control actions are required, the central control unit orders generator rejection to the terminal unit in the generators.

In this study, we focused on faults on 765 kV transmission lines that have tremendous affect on the Korean power system. It is requisite to update the logic of the SPS according to the change of power system conditions.

Acknowledgements

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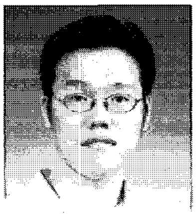

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