# Proposed Performance Criteria and Evaluation Procedures for Transmission System Planning in Korea

**Kyung Soo Kook*, Taihyun Kim*, Tae Kyoo Oh* and Min Jae Bang****

**Abstract** - This paper describes a proposed performance criteria and evaluation procedures for transmission system planning in Korea. Performance criteria of the transmission system are expected to be used as a guideline for investment into a transmission network. Moreover, performance evaluation procedures, which are based on current practices and widely accepted theories, are suggested to achieve fair and acceptable results.

## 1. Introduction

In a power system, from the view point of planning, the planning standard is required to be objective and documented clearly because it states minimum functional requirements which the power system should satisfy. This standard can also be used to determine when the appropriate time is for investment into an electric network. In Korea, as a wholesale electricity market is soon to be introduced, it has been requested that the existing planning standard be reviewed and documented more objectively together with its rationale. In other countries that have introduced competitive electric power markets earlier, the performance criteria were published in the form of a specified document and have been periodically reviewed and updated by the specified study group.

This paper describes proposed performance criteria for transmission system planning in Korea. Performance criteria are a set of least technical requirements for a transmission system that must be satisfied in the system planning process, and will be applied as objective criteria to various disputable conditions anticipated in the competitive electricity market.

The proposed performance criteria have been developed by taking into account characteristics of the Korean power system obtained through KEPCO(Korea Electric Power Corporation)'s practical experience in system planning. For doing this, performance levels are defined depending on their allowable actions and effects when subjected to a disturbance, and then performance criteria for each performance level are specified in terms of transient voltage, transient frequency, system damping, post transient voltage deviation, and loadings. This paper also presents evaluation procedures that will be used for checking whether a planned power system meets the performance criteria. Transparent evaluation procedures should be established since the evaluation results can be greatly affected by the evaluation procedures although the planner's discretion may be allowed to some extent. The evaluation procedures proposed in this paper are based on the basic principle that they can be implemented using general power system analysis programs.

* Electrical Testing and Research Laboratory, Korea (ROK). (kskook@keri.re.kr, thkim@keri.re.kr, tkoh@keri.re.kr)

** Power Grid Planning Office, KEPCO(Korea Electric Power Corporation) Korea(ROK) (bmj@kepco.co.kr)

Received October 11, 2002 ; Accepted November 18, 2002

## 2. Background to Performance Criteria

### 2.1 Development of Performance Criteria

Performance criteria for transmission system planning are determined based on the degree to which a transmission system should maintain the service of a supply of electricity to loads when subjected to disturbances. However, load supplying may be interrupted by the system operating practices as well as by deterioration of the electricity supplying service. So, performance criteria should consider both of these aspects.

The power system in Korea has been designed, constructed, and operated to maintain a high level of reliability that would not allow the loss of loads in the other areas outside where subjected to disturbances. Thus, in this paper, performance criteria for transmission system planning are proposed to assure this principle.

### 2.2 Performance Criteria for Normal State

A normal state is a state in which all the system elements are in service after the power system is adjusted to supply a load following operating procedures, and in which no faults or outages occur. For this normal state, performance criteria should meet the normal operating criteria that the system operator would apply to a power system operation.

## 2.3 Performance Criteria for Abnormal State

### 2.3.1 Classifying Performance Level

The performance level is classified based on the allowable actions or conditions on systems other than the one where a disturbance occurs.

In this paper, following the reliability criteria principle of Korean power system operation, no loss of load is allowed at any performance level. Table 1 shows each performance level defined by the allowable actions or conditions of the system.

**Table 1** Performance level

| Level / Allowance | PA-1 | PA-2 | PA-3 | PB-1 | PB-2 | PB-3 |
|---|---|---|---|---|---|---|
| Tripping Generator | NO | NO | NO | YES | NO | YES |
| Generation Output Adjustment | NO | YES | NO | NO | YES | YES |
| Temporary Loss of Load | NO | NO | YES | YES | YES | YES |
| Loss of Load | NO | NO | NO | NO | NO | NO |

*Temporary loss of load : Case of the dropped load being restored within a short period of time by switching actions at the station where the load is supplied.

In this table, a "YES" indicates that the actions or conditions are allowed in a simulation test to meet the performance level, and a "NO" indicates that the actions or conditions are not permitted.

### 2.3.2 Classifying Contingencies into Performance Levels

Selections of the considered contingencies are based on the probability of that contingency happening. Moreover, special considerations are given to characteristics of the Korean Power system in this paper.

In general, contingencies have different effects on the power system according to the functions of the transmission system where contingencies occur. Thus, according to this criteria a transmission system is divided into some categories according to its main function and its voltage level. The followings are defined to categorize the power system depending on its main function. Terms used in these definitions are referred to as the 'Electric Power Transmission Facilities Usage Rule' published by KEPCO.

- Generator connection system : transmission facilities connecting a generating unit to the main system
- Main system : transmission facilities connecting a generator connection system and load supplying system.
- Load supplying system : transmission facilities connecting load to the main system.

Table 2 shows contingency classification in each categorized transmission system.

**Table 2** Contingency classification

| Performance Level | Generator connection system [kV] | | | Main system [kV] | | |
|---|---|---|---|---|---|---|
| | 154 | 345 | 765 | 154 | 345 | 765 |
| PA-1 | ▤ | ▤ | - | - | - | - |
| PA-2 | - | - | - | ▤ | ▤ | - |
| PA-3 | - | - | - | - | - | - |
| PB-1 | - | - | - | ▤ ▤ | - | - |
| PB-2 | - | - | - | - | ▤ ▤ | ▤ |
| PB-3 | ▤ ▤ | ▤ ▤ | ▤ | - | - | - |

**Table 2** Contingency classification (continued)

| Perfor-mance Level | | Load supplying system [kV] | | M. Tr [kV] | |
|---|---|---|---|---|---|
| | 154 | 345 | 154 | 345 | 765 |
| PA-1 | - | - | - | ▤ | ▤ |
| PA-2 | ▤ | ▤ | - | - | - |
| PA-3 | - | - | ▤ | - | - |
| PB-1 | ▤ ▤ | ▤ ▤ | - | - | - |
| PB-2 | - | - | - | - | - |
| PB-3 | - | - | - | - | - |

▤ : Failure of 1 circuit or 1 Transformer Bank.

▤ ▤ : Failure of 1 route of 2 circuits.

In table 2, the failure of 1 route is not applied to the 765kV transmission line under the assumption that its probability is too low to consider into the criteria.

### 2.3.3 Transient Voltage Criteria

#### 2.3.3.1 Over Voltage

It was reported that over-voltage criteria are not required as a performance criterion[1], and are not recommended since they are usually related to a local problem

#### 2.3.3.2 Under Voltage

Table 3 shows the voltage dip criteria applied by WSCC to avoid uncontrolled loss of load[1]. In this table, the values were based on the estimated response of electronic equipment such as computers to voltage dips. In this paper, it is assumed that the electronic equipment in Korea has similar characteristics, so the values of this table can be applied as under-voltage criteria. But, only A and B steps in this table would be applied as the criteria here since the Korean power system would not allow any loss of load.

**Table 3** Voltage dip criteria comparing loss of load

| Step | Instantaneous voltage drop | Maximum duration of V dip exceeding Min. drop | Loss of load |
|---|---|---|---|
| A | 25% | 20[cycle] | No |
| B | 30% | 20[cycle] | No |
| C | 30% | 40[cycle] | Critical |
| D | 30% | 60[cycle] | Yes |

### 2.3.4 Transient Frequency Criteria

#### 2.3.4.1 Over-frequency

Over-frequency problems are mostly associated with generators, but generators usually have local protection. So, it is reported that over-frequency criteria are not recommended in the planning standard[1].

#### 2.3.4.2 Under-frequency

Under-frequency criteria are chosen to coordinate with the operational strategy for UFLS(under frequency load shedding). UFLS is expected to arrest frequency decline and avoid the cascading outage of load due to a disturbance. To end this, UFLS relay is set to be coordinated with under-frequency protection of generators and any other actions planned to occur when frequency declines.

In the Korean power system, UFLS relay is set at 58.8Hz. In other words, automatic load shedding starts if the system frequency declines below this value. In this paper, low-frequency criteria are proposed not to allow any loss of load on the assumption that this UFLS strategy is to be applied.

### 2.3.5 Post Transient Voltage Deviation

The criteria for post transient voltage deviation are set to provide some measure of the ability of system to recover to acceptable operating conditions following a disturbance[1]. It is also known that these criteria can provide some information about the incipient voltage collapse problem though these are not sufficient as voltage stability criteria. 5-10% deviation is usually recommended for this[1]. In this paper, this criterion would be applied.

## 3. Proposed Performance Criteria for Transmission System Planning[4]

### 3.1 Performance Criteria for a Mormal State

A normal state should meet the following performance criteria considering the operating criteria of the Korean power system.

① All transmission facilities should be within their thermal rating for normal state

② System frequency should usually be at 60Hz, and adjusted within 60±0.2Hz, otherwise an exception occurs.

③ Voltage in the transmission system should be within the following criteria in Table 4.

**Table 4** Voltage criteria for a normal state

| Voltage level | Voltage criteria | Remarks |
|---|---|---|
| 154kV | 156~164kV | Peak |
| | 152~160kV | Off-Peak |
| 345k | 336~360kV | - |
| 765kV | 746~785kV | - |

### 3.2 Performance criteria for a disturbance

A disturbance, in this paper, means a fault or outage of system elements that is unplanned. The response of the transmission system to this must meet its performance criteria. Table 5 shows the proposed performance criteria for each disturbance.

**Table 5** Performance criteria for a disturbance

| Performance level | Transient voltage dip(measured in a load bus) | Transient frequency(measured in a load bus) |
|---|---|---|
| PA-1 | - Maximum voltage dip : 25%<br>- Max. Duration of V dip exceeding 20% : 20cycle | - Minimum : 59.6Hz<br>- Max. duration of F below Min : 6cycle |
| PA-2 | Same as above | Same as above |
| PA-3 | Same as above | Same as above |
| PB-1 | - Maximum voltage dip : 30%<br>- Max. Duration of V dip exceeding 20% : 30cycle | - Minimum : 58.9Hz<br>- Max. duration of F below Min : 6cycle |
| PB-2 | Same as above | Same as above |
| PB-3 | Same as above | Same as above |

**Table 5** Performance criteria for a disturbance (continued)

| Performance level | Damping | Post transient V deviation | Loading |
|---|---|---|---|
| PA-1 | Positive | 5% | Within nominal rating |
| PA-2 | Positive | 5% | Within emergency rating |
| PA-3 | Positive | 5% | Same as above |
| PB-1 | Positive | 10% | Same as above |
| PB-2 | Positive | 10% | Same as above |
| PB-3 | Positive | 10% | Same as above |

## 4. Proposed evaluation procedures[4]

The power system planned for the future should be evaluated to ensure that it meets the required performance criteria. This evaluation usually uses a simulation test, and results should be available in the electricity market. But, the test results generally depend on process and technique. Thus, evaluation procedures need to be specified in a reasonable and objective way. In this paper, the proposed evaluation procedures are based on basic principles that can be implemented using general power system analysis programs.

### 4.1 Overview

In simulation test, it is important to model physical systems correctly and apply practical operating processes. Table 6 shows the overview of proposed procedures for simulation test.

**Table 6** Overview of simulation test procedures

| |
|---|
| 1. System analysis for a normal state |
| 2. Define Base Case |
| 3. Define Contingency set |
| 4. Assign performance criteria to contingencies |
| 5. Simulate a response of system to contingencies |
| 6. Decide if its response meets each performance criteria |
| 7. Simulate again considering any actions allowed to improve system's response if its response does not meet criteria in step 6. |
| 8. Report simulation test results |

### 4.2 Base case

A base case is a normal state which would be used as a basis in a simulation test. For a given system, a base case is defined as a normal state which meets the following requirements.

① Generating output of generating unit at slack bus is also within its generating capacity.

② Each voltage of all buses is within the operating range

③ Each loading of all branches is within its normal rating.

④ Each loading of all facilities such as a transformer is within its normal rating.

For the purpose of practical study, adjusting generating output of generating units and tap ratio of the transformer are allowed to meet the base case requirements.

### 4.3 Contingency set

Contingency for a simulation test is selected corresponding to each performance level. For this, the following principles should be applied.

① A contingency set should be selected for each year, each voltage level, and each performance level considering its probability of occurrence, and severity. And this set must be reported, and should include the following.

I. Failure of 1 circuit in all lines of which voltage level is above 154kV

II. Failure of 2 circuits(1 route) in all lines of which voltage level is 345kV(In the case of cable, failure of only 1 circuit is considered.)

III. Failure of 2 circuits(1 route) in all lines of which voltage level is 154kV(In the case of cable, failure of only 1 circuit is considered.)

② The contingency is simulated at a point where its effect would be most severe.

③ The contingency of a line is simulated as a 3-phase fault or line to ground fault of 1 circuit

### 4.4 Post transient power flow

Post transient time frame usually means 1 to 3 minutes after a disturbance occurs, and this does not include manual actions but automatic actions are considered.

#### 4.4.1 Power flow method

The following process is recommended to improve its convergent characteristic in the power flow calculation

① Newton-Raphson calculation with flat start

② Gauss-Seidel calculation with solution of step 1

③ Newton-Raphson calculation with solution of step 2

#### 4.4.2 Voltage deviation

Voltage deviation of buses after a disturbance occurs is calculated using the following equation.

Voltage deviation[%] = ( | bus voltage after a disturbance occurs – bus voltage in base case | ) / ( bus voltage in base case ) × 100

### 4.5 Transient analysis

The simulation test considers automatic relay action, time frame of fault clearing, and reclosing of relay for transient analysis. For this, the followings principles are applied.

① Transient stability is determined by whether the generating unit can keep synchronized operation through the simulation for a power angle characteristic curve

② The simulation period for determining transient stability should be longer than 3 seconds after a fault is cleared to monitor the first or second swing at least in the power angle curve.

③ In the case of a line fault, a relay is considered to open that line by its automatic action, and a reclosing relay is not considered.

④ The fault clearing time of main protection system is as follows.

- 154kV line : 100ms(6 cycle)
- 345kV line : 100ms(6 cycle)
- 765kV line : 66.7ms(4 cycle)

⑤ For a transient voltage dip, the simulation test should check all load buses.

⑥ For minimum transient frequency, the simulation test should check all load buses.

⑦ For transient stability, the simulation test checks the angle-spread between the maximum angle and minimum angle of the generating unit in the system. Positive damping is principally defined as the case in which athe line connecting tops and the line connecting valleys in the power angle curve cross each other. But, it is usually known that synchronism between generating units can not be maintained if the angle spread becomes larger than 180[deg].

## 5. Conclusion

This paper proposed performance criteria for transmission system planning in Korea. To do this, the basic principle of the planning standard of NERC/WSCC is studied in comparison with the practices in transmission system planning in Korea.

An evaluation test should be specified in a reasonable and objective way while a more detailed process should be flexible enough to include all the possible variations. Performance evaluation procedures are also proposed as a guideline for a simulation test based on this principle.

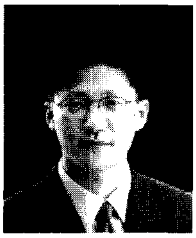
We consider that the performance criteria should be reviewed and updated to reflect the changing requirements of the electric power industry. So, it is necessary for an independent committee to be established to review the performance criteria periodically.

## Acknowledgement

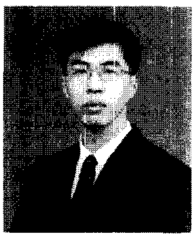
This work was sponsored by the Power Grid Planning Office, KEPCO(Korea Electric Power Corporation).

## Reference

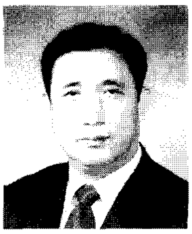
[1] J. Kondragunta, SCE and WSCC Reliability Subcommittee, “Supporting document for reliability criteria for transmission system planning”, August 1994.
[2] “NERC/WSCC Planning Standards”, NERC, 1997.
[3] “Planning criteria for long term power system planning”, KEPCO, 1999.
[4] “A study on criteria and standards for transmission system planning”, KEPCO/KERI, August 2001
[5] Mohan K. Pandey and Roy Billinton, "Electric Power System Reliability Criteria Determination in a Developing Country", IEEE Transactions on Energy Conversion, V.15 N.3, September 2000.
[6] Mohammed J. Beshir, SM, “Probabilistic Based Transmission Planning and Operation Criteria Development for the Western Systems Coordination Council”, IEEE/PES Summer Meeting Panel Session, Reliability Criteria for Transmission System Operation and Planning under Restructuring, 1999.



**Kyung Soo Kook**
He received his B.S. and M.S. degrees from Korea University, Seoul, Korea in 1996 and 1998, respectively, both in electrical engineering.
Since 1998, he has been a researcher at KERI, the Korea Electrotechnology Research Institute. His main areas of interest are Power System Analysis, FACTS Applications, Optimization Techniques Applied to Power System, and Electricity Market Operation.
Tel: +82-31-420-6137



**Taihyun Kim**
He received his B.S. degree from the Korea Advanced Institute of Science and Technology(KAIST) in 1989, and his M.S. and Ph.D. degrees from the University of Maryland, College Park, in 1994 and 1998, respectively, all in electrical engineering.
He was an assistant researcher scientist at the Institute for Systems Research, University of Maryland, during 1998-1999. Since 1999, he has been a senior researcher at the Korea Electrotechnology Research Institute(KERI). He is pursuing research in nonlinear system analysis and control with application to electric power system, and in competitive electricity market.
Tel: +82-31-420-6132



**Tae Kyoo Oh**
He received his B.S. degree from Seoul National University, Seoul, Korea in 1978, and M.S. and Ph.D. degrees from Iowa State University, in 1984 and 1986, respectively.
Since 1987, he has been with KERI, Korea Electrotechnology Research Institute. Now, he is Director of Electrical Testing & Research Laboratory, KERI. He has been actively involved in the research of Power System Analysis and Control, FACTS Technology Applications, and Electricity Market Technology. He is a member of KIEE, IEEE, and CIGRE.
Tel: +82-31-420-6003

**Min Jae Bang**
He received his B.S. and M.S. degrees from Korea University, Seoul, Korea in 1983 and 1985, respectively, both in electrical engineering.
Since 1985, he has been with KEPCO, the Korea Electric Power Corporation. His main area of interest is Transmission System Planning.
Tel: +82-2-3456-5221