The regional Power System Models

1. Objective and Overview of Regional Power System Models

Japan's regional power system (77 and 66 kV) has been modeled. These three main types of models are described as bellows;

- Model I : 77 kV Provincial system model (77kV Overhead transmission system)
- Model II : 77 kV Metropolitan system model (77kV Cable transmission system)
- Model III : 66 kV Suburban system model(66kV Mixed overhead line and cable system)

It is hoped that you will clearly demonstrate the numbers, such as Model I, the names of the systems in the parentheses, or the title of this paper whenever you quote this paper.

The formulation of these models has embodied the upshot of the survey, which was conducted by a questionnaire to the committee members. Since there was a time limit, we were forced to make a modification as follows;

1.1 Objectives of Application

With the upshot of the questionnaire, the application objectives were narrowed and selected in ascending order of their needs as follows;

(i) performance verification of failure-recovery mechanism/system switching algorithms
(ii) performance verification of reliability assessment technique
(iii) performance verification of optimum layout technique for distributed power supplies

Formulation methods are described in the section that follows and proved the above three system models can attain the objective (i). Model III has already attained the objective (ii). As for (iii), all of the basic data on the capacity of transmission lines and loads are available, however, any of the specific verifications have not been performed yet.

1.2 Features of Models

1.2.1 Overhead line system (Model I)

This model is dotted with small-scale hydropower plants and suited for the study of optimum combination when a failure occurs since power supply substations are well networked with overhead lines and the power supplies enable to changes in the output.

1.2.2 Cable system (Model II)

This system is designed for downtown where high reliability is required thus cable lines are adopted. The configuration of the system is on the precondition that lightening strikes would cause no power failure thus lower failure rate. However, when a large scale of the system failure would occur once, it is expected that 77 kV system switching alone will not be able to avoid service problem. Therefore distributing switching is added to indicate the amount of switching 77kV system and the distribution systems were also taken in the model.

1.2.3 Mixed Overhead Line and Cable System (Model III)

This system is designed for a suburban area where commercial (cable transmission systems), industrial, residential (overhead transmission systems) neighborhoods are mixed. To perform reliability assessment, hourly load data on failure rate and three kinds of loads of commercial, industrial and residential neighborhoods are available for one year together with failure-recovery mechanism data.

The data are for a fault-recovery mechanism of the system models and have some redundancies since the data deals with multiple applications. Therefore other system models are also provided which are not for the study of a failure-recovery mechanism.

1.3 Utilization of Models

This was for the first time to formulate models, and needless to say, they need further modification since there are still some difficulties to carry out those application objectives. Some researchers had demanded to take many factors in data to restore as nearly real the state of existing systems as possible so that it led the models to acquire unnecessary information for application objectives. Furthermore, the models might become complicated and difficult to use.

Therefore, it is not necessary to use the whole data when processing the models. Just use only part of the data or change the load levels according to your study objective. We sincerely ask your favor that you will state clearly out in your paper, which parts of these models are quoted, omitted, or modified. Since researchers' common concern should be the formulation of the model.

It should be noticed that the models are “standard” models, however, all of the data do not necessarily represent the standard value of Japan. For instance, permissible time of short-time capacity ,failure rate and recovery/system switching time varies by electric power utility companies in Japan, thus there is no “standard.” The values for the models are based on the values that are adapted by a certain electric company, thus they are practical values but not “standard values in Japan.” Attention should be given to the above facts whenever you will make an oral presentation overseas and refer to the models.

2. Regional Power System Models

2.1 Model I : 77kV Provincial system model (77 kV Overhead Transmission System)

The system models have been formulated as large-scale models that will be mainly used for a study of the system failure-recovery mechanism as well as a study of large-scale failure-recovery. Depending on the subjects, you could choose between two of the load cases.

2.1.1 Concept of System Model

The system model is based on 77 kV system with a primary bus of the power supply substations. The system model is shown in Fig. 2.1 and 2.2 and described the overview as follows;

(1) System

The system is comprised of 12 power supply substations and transmission lines connecting each of the power substations, receiving and distribution substations (the remainder of this paper will describe as linked substations) with line switching devices, and small-scale hydropower plants. Each system is bifurcated into two at linked substations or power supply substations. Distribution substations bifurcated from the transmission lines and large volume customer are unified.

Table 2.1 Scale of Model I

Number of power supply substations/total capacity of facilities		12 stations/ 6,337 (MW)
Number of hydropower plants/linked substations		21 stations
Output power		39 - 99 (MW)
Description	Variable output	10 - 70 (MW)
	Fixed output	29 (MW)
Number of linked transmission lines		48 routes
Amount of electrical demand	Standard load case	5,041 (MW)
	Increased load case	5,351 (MW)

In a geographical sense, the system is largely classified into a mountain-ringed region or a left side of the hillside, and a base where almost all of the customers live. The system that run through the mountain-ringed region connects weakly and hydropower plants are situated in parallel. The heaviest concentration of power supply substations of multiple systems is around the area where many customers live.

(2) Load Case

The system model provides with two different cases of load.

(a) Standard load case is given in Fig. 2.1

For the case, load is set as nearly real load as possible.

Application example: minimization of recovery time, etc.

(b) Increased load case is given in Fig. 2.2.

For the case, some loads are set by large amounts while decreasing the reserve capacity of facilities. Thus load has a large amount of remaining service problem after the failure-recovery mechanism is performed.

Application example: minimization of service problem, etc.

2.1.2 System Data

For the system models, the following data are shown in the diagram.

(1) Power Supply Substations

(a) Transformer continuous capacity (MW): It shows individual transformer and the amount value of continuous capacity. The amount value where impedance does not match is the value that takes into account of impedance ratio.

(b) Transformer proactive current limitation (MW): It shows continuously transformer current limitation value that is determined by transformer overload pattern shown in Fig. 2.3 and 2.4.
(c) Transformer impedance (%/10 MVA base): It shows impedance value of individual transformer based on 10 MVA.
(d) Secondary bus configuration: It consists of double buses and shows the bus connecting status of each transformer, transmission line and load.
(e) A phase difference: It shows the phase difference of each primary bus of power supply substation against primary bus of No.1 substation.

(2) Linked substations

(a) 77 kV bus configuration: It consists of either double bus or single bus configuration and the part of the double bus shows bus connecting status of each transformer, transmission line and load.

(3) Linked transmission lines

(a) Continuous capacity (MW): It shows continuous capacity value of each line.
(b) Short-time capacity (MW): It shows short-time overload value of each line that is determined by transmission line overload pattern shown in Fig. 2.5.
(c) Impedance (%/10 MVA base): It shows impedance value (x component only) of one line on 10 MVA base.

(4) Load

Recovery priority: Each load was classified into 3 groups and arranged in order of decreasing precedence as I, II, and III.

2.1.3 Constraints

(1) Proactive Current Value of Transformer

Current flowing through the transformers of power supply substations should be within the proactive current limitation when multiple transformers are working in parallel, and within continuous capacity when single transformer is working.

(2) Proactive Current Value of Transmission Lines

Current flowing through the linked transmission lines should be within short-time capacity of one line when two lines are in service, and within continuous capacity when single line is in service.

(3) Current Value of Transformer when a Failure Occurs

When one of parallel connected transformers breaks down, current of the remaining transformer should be within the overload pattern as shown in Fig. 2.3 or 2.4, and when it is not within the pattern, then interrupt the load. When performing recovery from the adjacent system, current flowing through the transformers of adjacent substation should be within continuous capacity.

(4) Current Value of Transmission Lines when a Failure Occurs

When one of parallel connected transmission lines suffers a breakdown, current of the remaining transmission line should be within the overload pattern as shown in Fig. 2.5, and when it is not within the pattern, then interrupt the load. When performing recovery from its adjacent system, current flowing through transmission lines of adjacent linked system should be within continuous capacity.

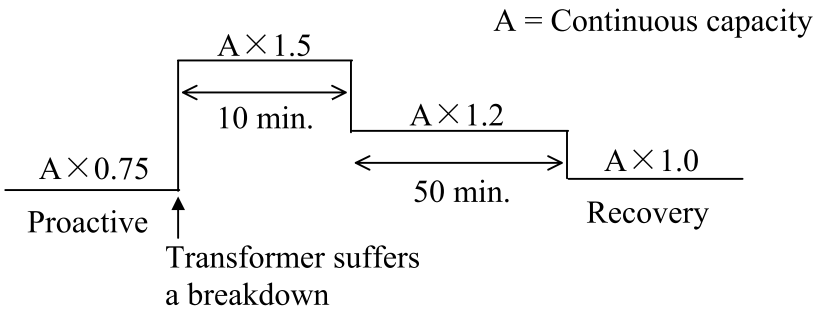

Fig. 2.3 Overload Pattern of Transformer (Two parallel connected transformers)

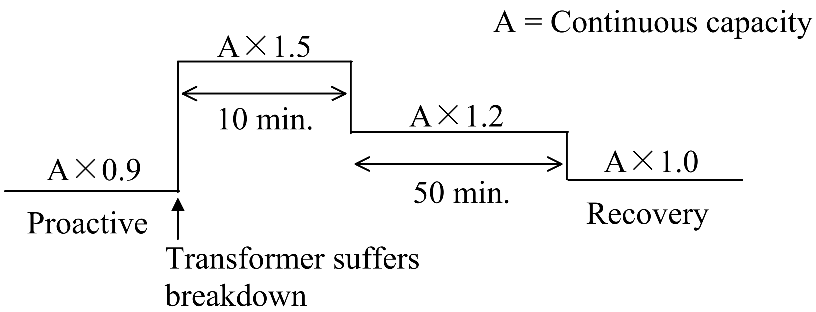

Fig. 2.4 Overload Pattern of Transformer
(More than two parallel connected transformers)

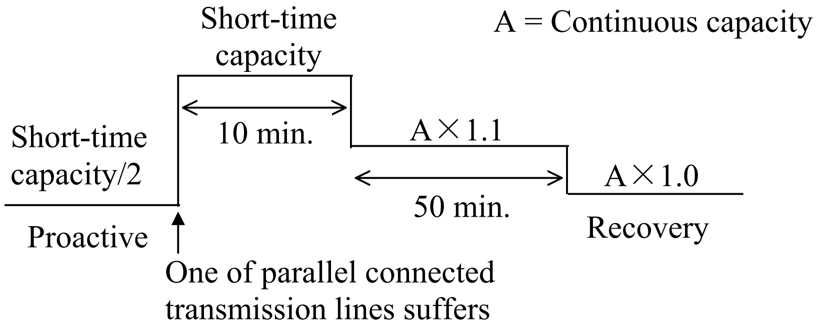

Fig. 2.5 Overload Pattern of Transmission lines

2.2 Model II 77 kV Metropolitan system model (77kV Cable Transmission Systems)

The models that are made up mainly cable systems were formulated for the study of a failure-recovery mechanism in large metropolis areas. In addition to system switching as a means of recovery mechanism, distribution line switching is also included.

2.2.1 Overview of System Models

The systems are designed for downtown where cable lines are adopted. The power supply substations which receive power from the high level system are situated nearby downtown, and the distribution substations receive power from these power supply substations. (Fig 2.6)

The systems are comprised of 6 power supply substations, 2 linked substations, 1 switching station, and 27 distribution substations. The system configuration is in a radial symmetry and distinguishes the system at a continuous open point. Therefore it is possible to limit a power failure area when a power supply substation suffers a breakdown, and supply power from its adjacent system when failure-recovery mechanism is fully operational.

2.2.2 System Data

All of the system data are shown in the system diagram. The details on data items are as follows;

(1) Power Supply Substation

(a) Continuous capacity (MVA): It describes the continuous capacity of the transmission transformers. The amount of the values become equal to substation capacity.

(b) Large-volume end users' load (MW): Node number and load value is described the load directly receiving from transmission substations.

(c) Secondary bus configuration: Every substation is comprised of double or triple buses, and the bus configuration is indicated either with a closing of the bus-connected switchyard or presentation of the opening. Closing facility is indicated with 'CircleO' while opening facility with 'CrossX'.

Table 2.2 Configuration of Cable Transmission System

Number of power supply substations/ total capacity of facilities	6 stations 3200 MVA
Number of linked substations	2 stations
Number of switchyards	1 station
Distribution substations	27 stations
Number of large volume customer	15 stations
Number of transmission lines	48 routes
Total capacity of facilities on the demand side/ total quantity of demand	1900 MW 1370 MW

(2) Distribution Substation

(a) Load (MW): It indicates the value of the initial load.

(b) Continuous capacity (MW): It indicates the value of the maximum capacity of the substation.

(c) Load switching destination: Distribution substations with distribution switching shows the destination with an arrow. When one of the substations suffer a breakdown, it is possible to shift the load to another working substation.

(d) Phase difference: The phase difference between the secondary buses of the power supply substation against the secondary buses of transformers of substation No.1.

(3) Transmission Line

(a) Continuous capacity (MW): It indicates the transmission capacity per line as continuous permissible value.

(b) Short-time capacity (MW): It indicates the transmission capacity per line as short-time permissible value within 10 minutes.

(c) Impedance (%): It describes the impedance per line of transmission lines on 10 MVA base. When it comes two or more than two lines in parallel, then impedance only describes the value of one line since impedance has the same value.

(d) Switchyard facilities: Transmission lines of closing switchyard are omitted in the diagram and only opening switchyard facilities are marked 'ClossX'.

(4) Recovery Priority

Each load is classified into 2 groups and load in order of decreasing precedence is shown as I while the other is shown as II.

2.2.3 Constraints of Failure-recovery Mechanism

(1) Failure-recovery Mechanism Procedure

For a study of the failure-recovery mechanism, it is assumed to switch over the system and distribution lines in resolving such an overload against a power supply substation failure, then to recover from a power failure.

For recovery procedure, firstly switch over from the broken-down 77 kV system to a working one. When the switchover did not resolve the overload or recover from a power failure area, then perform a distribution switching to shift some load.

(2) System Operation Conditions

This system maintains constant voltage at the parts of the systems so that it enables Direct Current Power Flow Calculation. Since there is no limitation of voltage, the switchover of switchyard facilities to 77 kV system can be performed anytime. However, ultimate systems are to be configured at each power supply substation and these power supply substations should not be linked one another.

The concept in the section 2.1.3 can be applied to the short-time overload capacity of power supply transformers and transmission lines, and its available time. Proactive current of the transmission lines should not exceed the value of the short-time capacity when a n-1 failure occurs.

The destination of load is predetermined when switching over the distribution lines and up to 30MW per destination should allow switchover. However, it should not exceed the maximum value of continuous capacity of each distribution substation.

The following are a recovery procedure.

(a) Procedure

(i) Switch over 77 kV systems.

(ii) Switch over the distribution lines when the system switchover is not enough to prevent overload of lines.

(b) Conditions

(i) Switching over the distribution lines should be performed the loads to each switching destination. Up to 30MW per destination should allow switchover.

(ii) It should not exceed the maximum value of continuous capacity of each distributing.

(iii) Distribution line switching should be performed the load from a broken-down section to working section. Do not perform the load switchover between the working sections.
(iv) Ultimate systems should be configured at each power supply substation. Do not connect power supply substations one another.

2.3 Model III 66kV suburban system model (66 kV Mixed Overhead Lines and Cable System)

The system models are for the sake of both a study of a failure-recovery mechanism and a reliability assessment. The system models took in many factors to restore as nearly real the systems as possible where industrial, commercial and residential areas are mixed and a common scene in suburban areas of Japan.

2.3.1 Overview of the System Model

The cross-sectional view of load of this model at 15:00 p.m. during the summer is shown in Fig. 2.7. The scale of the system is described in Table 2.3 as below;

Table 2.3 Scale of Model III

Number of power supply substations/ total capacity of facilities	4 stations 2700 MVA
Number of 66 kV linked substations	8 stations
Distribution substations*	38 stations
Number of large volume customer	95 stations
Number of transmission line routes	37 routes
Total capacity of facilities on the demand/ total amount of demand	2430 MVA 1680 MW

* Including linked substations

The models cover from the primary buses of the power supply substations either to the secondary transformers of the distribution substations, or to the primary (66 kV) bus of the facilities of large volume customer. The system has 4 power supply substations and normally one of power supply substations has divided bus. As for 66 kV system, it is divided into 5 systems and operated in a radial pattern. The breakdown of the demand is as follows; 50% for residential load, 25% for commercial load, and 25% of industial load.

2.3.2 Data for Study of Failure-recovery Mechanism

This system model data are listed in Table 2.4 and 2.5. 7 of data items are as follows;
(a) Node data [Table 2.4 (a)]

(b)	Transmission line data	[Table 2.4 (b)]
(c)	Switchgear data	[Table 2.4 (c)]
(d)	Transformer data	[Table 2.4 (d)]
(e)	Voltage compensator data	[Table 2.4 (e)]
(f)	Load curve data	[Table 2.5 (a)]
(g)	Failure rate/recovery time data	[Table 2.5 (b)]

Individual data item in detail is described in the tables. Loads are defined for each transformer of the distribution substations. In the system diagram, each distribution substation is expressed in the unit.

This simple data are available for the study of a failure-recovery mechanism. To be more specific, loads are accumulated at each section on transmission lines and distribution substations together with large volume customer were taken in up to the receiving substations.

2.3.3 Constraints when Study of failure-recovery Mechanism

Short-time capacities of transmission lines and transformers together with their available time are indicated in Fig 2.8.

There are two constraints of a failure-recovery mechanism; current should not exceed the short-time capacity of facilities during the failure-recovery process; and current should not exceed the continuous capacity of facilities after recovery.

Facilities	Short-time capacity	Overload pattern
Transmission lines	Being set individually	See Fig. 2.5
Distributing transformers	150% of continuous capacity	See Fig. 2.8
Other transformers	120% of continuous capacity	See Fig. 2.4

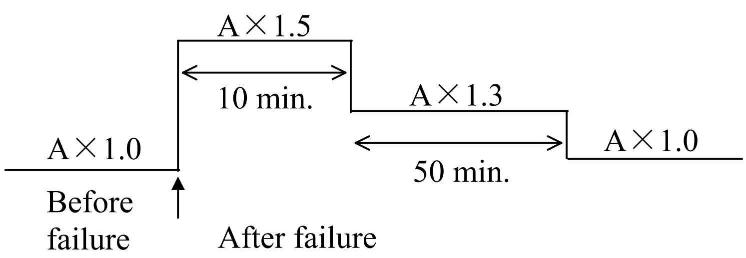

Fig. 2.8 Overload Pattern of Distribution Transformers

2.3.4 Data for Study of Reliability Assessment

Node/Branch data as described in Chapter 2.3.1 together with failure rate of facilities data will be needed to evaluate reliability, such as service problems and time. Apart from a failure-recovery mechanism, service reliability will be changed depending on whether switching to other facilities is possible or not, thus facilities capacity data together with a time-varying demand data will be needed.

IEEE Reliability Test System earns an excellent reputation as an existing system model for reliability assessment. The model together with transmission line system models provide necessary data for reliability assessment, such as power supply characteristics, demand model and failure rate.

This model does not take power supply characteristics into account since it is intended for the reliability assessment of regional power system model. For demand model, it is set to enable not only an across-the-board load assessment, but also individual load assessment since load fluctuation data ensure reliability assessment.

(1) Load Fluctuations Data (Demand Model)

As shown in Table 2.5(a), load fluctuations data is classified as residential load, commercial load and industrial load and load fluctuations of 8,760 hours (one year) can be set with daily load curve (classified into weekdays and holidays) and monthly load level. Since the residential load varies with season, 3 kinds of daily load curve; summer, winter and spring/fall, are prepared. Node data indicate where loads in Fig. 2.7 are classified. [Table 2.4 (a)]. The load curves are shown in Fig. 2.9 (a) through (e). Apart form monthly load data, 5-days out of late July were specially indicated (shown as “P” in Table 2.5(a)) to point out Japan’s electricity use at a time of peak demand. Monthly load level is shown in Fig. 2.9 (f).

Annual duration data for the system are also available for the users who do not need to take load types into account. The data enable users to obtain an across-the-board load and to perform assess reliability.

(2) Failure rate/Recovery time data

Failure rate is shown in Table 2.5 (b). The failure rate is based on the values indicated in “Advancement and Efficiency of Maintenance for Substations” (50, No. 2) by Denki Kyodo Kenkyu and actual values from some electric power companies. The failure rate of buses of substations and distribution substations were equated. When transmission line recovery would fail, then recovery time does not mean time to recover the facilities, but time to construct the systems free from service problem by adopting distribution line switching.

(3) System Switching Time

In this system, system switching was taken into account and assumed that service problems would be solved quickly. Thus switching time is determined as follows to improve reliability assessment.

- Receiving substation switching of the primary of distribution substations 1 minute
- Bank switching of distribution substation 10 minutes
- Other switching: Operating time for switching should be 5 minutes together with 3 minutes of initial response. Thus power failure time will be (3 + 5N) minutes to complete N times of the system switching until it would resolve a service problem.