

CHAPTER 3

THE DESIGN OF EVALUATION MODEL FOR SAIDI TARGETS OF REGIONAL TRANSMISSION SYSTEMS

3.1 Introduction

Taipower' transmission system is divided into the primary and the secondary transmission systems. The former refers to the 345 kV and 161 kV transmission systems which include the relevant lines and substations such as the 161/22.8 kV substations; the latter refers to the 69kV transmission lines and the 69/11.4 kV substations.

The 345 kV and 161 kV transmission systems are designed on basis of a variety of rules including the N-1 and the N-2 rules. Thus, if the network status during operation can meet the N-1 or N-2 design rule, the network fault generally shall not cause any service interruption. However, during operations some expected design conditions may not be all realized. As such, service interruptions are commonly not avoidable.

In addition, some 69/11.4 kV substations, particularly those at the rural area , and most 69 kV feeders are N-0 designed, which means that the substations and the feeders are both radically configured, or have their downstream 69 kV customers supplied with a single 69 kV feeder only. Furthermore, some 161/22.8 kV main transformers in the primary distribution substations are unable to provide the N-1 load transfer capacity, particularly during the summer peak hours where their load factors already exceeded 70%. Under such situations, the fault can then cause service interruption to the utility's customers.

The main cause for the scheduled service interruption of transmission system is

due to the removal of a radically configured feeder or substation. Nevertheless, after proper coordination with customers by arrangement of feeder's or substation's overhaul period coordinated with the annual maintenance of customers' facilities, the scheduled service interruption can be effectively reduced. The SAIDI record of forced service interruption in 2003 accounts for 2.1979 min/customer-year. In the same year, the SAIDI record of scheduled service interruption accounts for only 0.0145 min/customer-year. Therefore, the scheduled transmission system interruption shall not be evaluated in this dissertation.

Referring to the 4 steps presented in Chapter 2 for setting the regional SAIDI (or SAIFI) targets, the AHP model for setting SAIDI targets of regional transmission systems can be designed by:

- (1) building the hierarchical structure for the relevant disparity factors of the evaluated regional transmission systems,
- (2) selecting proper evaluation indices to evaluate the disparities among regional transmission systems for each factor, and
- (3) designing questionnaires to obtain the relative weights of these factors.

In the following sections, the above 3 steps to build the AHP model as well as the disparity factors and their corresponding evaluation indices of the SAIDI for transmission forced service interruption shall be presented.

3.2 Disparity Factors of SAIDI for Transmission Forced Service Interruption

To identify the disparity factors which directly affect the SAIDI metric value of a regional transmission system caused by forced service interruption is not an easy task. As in contrast, if the SAIDI to be evaluated in Chapter 2 is decomposed to the

multiplication of 3 items as presented is Eq. 2-20 of Chapter 2, the evaluation problem can then be handled in a more systematic approach.

These 3 evaluation targets are:

- Average times of service interruption per year
- Average duration per service interruption
- Average number of customers affected per service interruption

Each evaluation target is affected by several disparity factors which can be arranged into a hierarchical structure. The following of this section shall enumerate the major influential factors and investigate their impact on the SAIDI for forced service interruption of regional transmission system.

Incidents that might occur at the transmission system are stemming from saline/dust hazards, lightning stroke, wind hazard, reptile/insect hazard, bird/mammal contact, public negligence, construction oversight, customer equipment failure, substation relay malfunction, equipment failure or deterioration, induced voltage on pilot relaying system, and so forth.

Besides management related measures taken to reduce the probability of occurrence stemming from the foresaid reasons, and taken into account the characteristics of various transmission offices, a further analysis has yielded other major factors that might affect the SAIDI metric values at various transmission service regions include:

- Weather environment (lightning/saline hazards),
- Total circuit length of transmission lines,
- Transformers' peak load rate,
- Radial circuit ratio,
- Customers' owned outdoor substations,
- Degree of customer's cooperation with Taipower in power restoration process.
- Geographical conditions (referring to urban area, suburbs, mountainous regions,

etc.),

- Overhead/underground transmission line count,
- Circuits' load transfer capability,
- Customer density and so forth.

The 3-layer AHP sub-model for evaluating the average times (denoted by $V_{j, \text{frq}}$ in Eq. 2-22) is shown in Fig. 3.1. The 3-layer AHP sub-model for evaluating the average duration (denoted by $V_{j, \text{drt}}$ in Eq. 2-22) is shown in Fig. 3.2. Also, the 4-layer AHP sub-model for evaluating the average number of customers affected (denoted by $V_{j, \text{ctm}}$ in Eq. 2-22) is shown in Fig. 3.3.

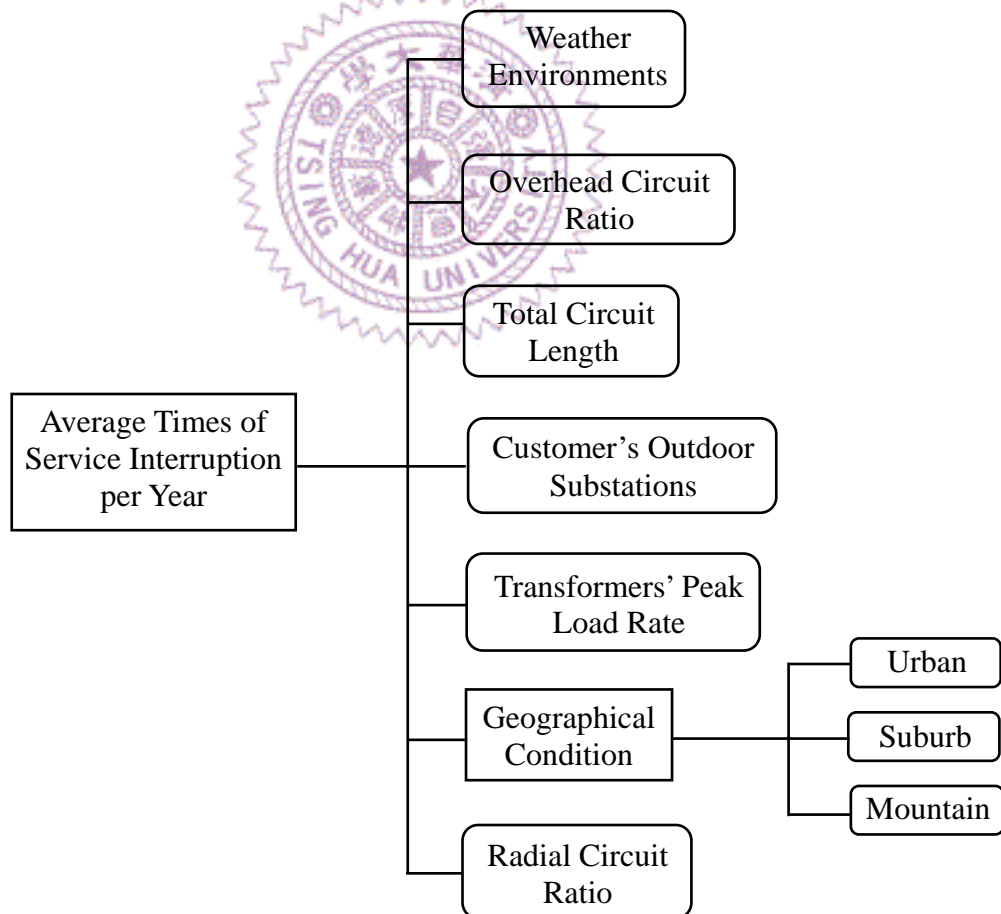


Fig. 3.1 The 3-layer model for evaluating $V_{j, \text{frq}}$ of transmission forced service interruption.

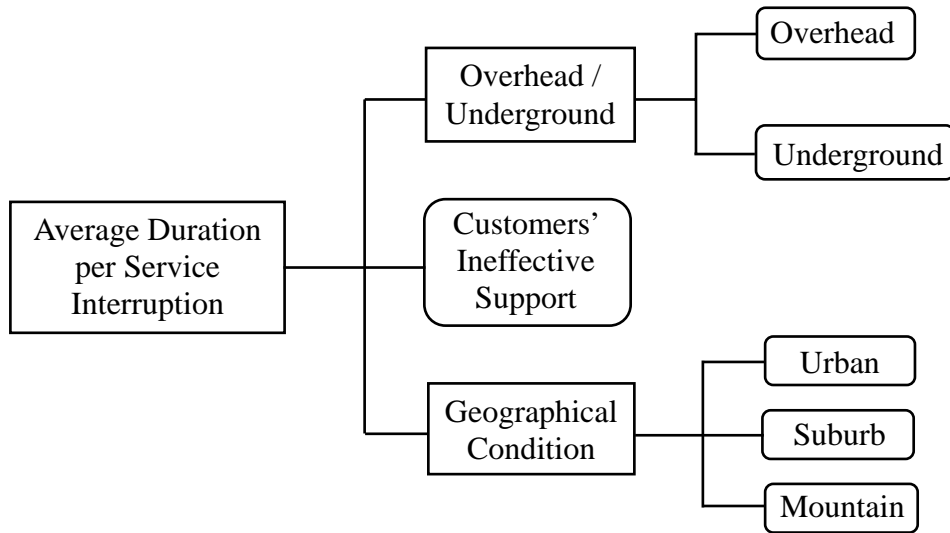


Fig. 3.2 The 3-layer model for evaluating $V_{j, \text{drt}}$ of transmission forced service interruption.

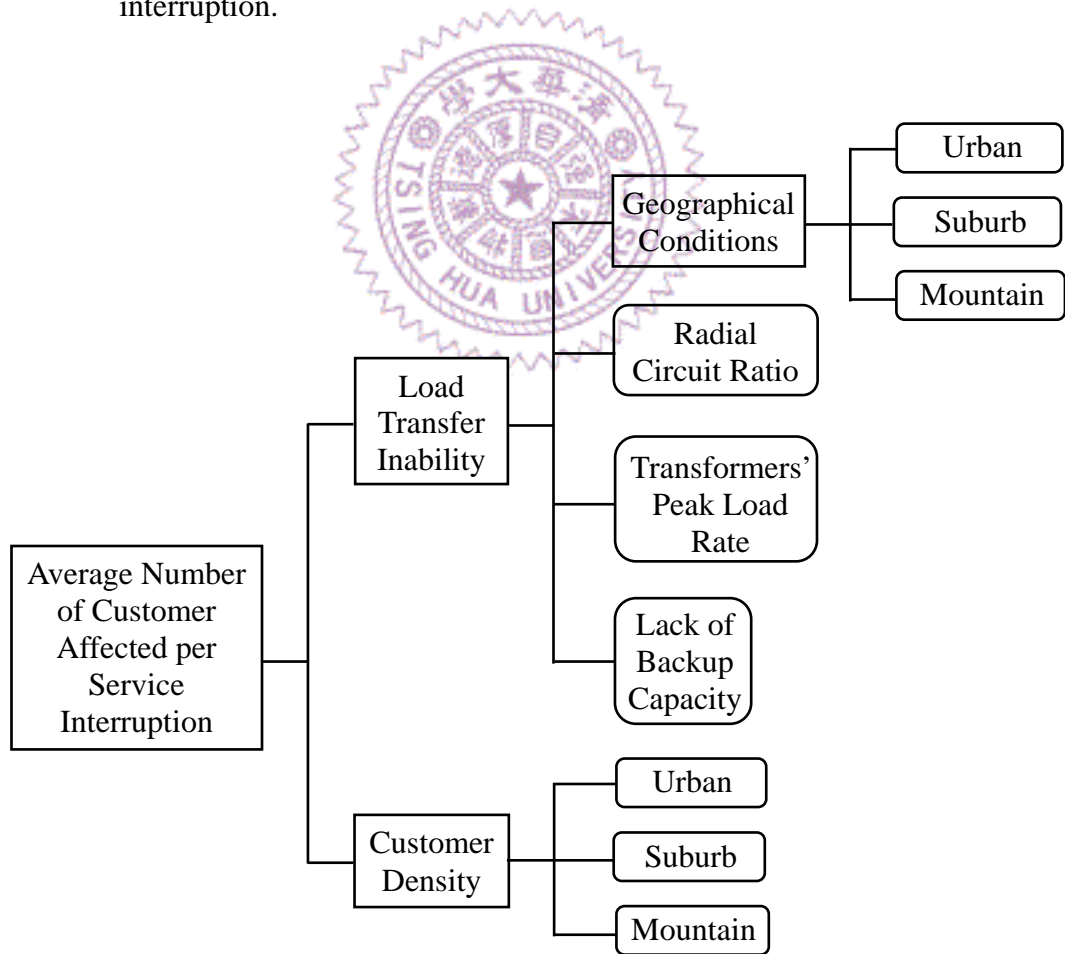


Fig. 3.3 The 4-layer model for evaluating $V_{j, \text{ctm}}$ of transmission forced service interruption.

These factors are detailed in following paragraphs.

(1) Weather Environments

Areas that are prone to severe lightning/saline/fog hazards tend to have a higher probability of forced power interruption.

(2) Overhead Circuit Ratio

Overhead transmission lines are more prone to faults yet require a relatively shorter time to repair, whereas underground feeders are less prone to faults yet require a relatively longer time to repair.

(3) Total Circuit Length

The longer a circuit runs, the higher the fault probability.

(4) Customer's Outdoor Substations

This factor is especially mentioned by Taipower's field engineers. Customer-owned substation faults are one of the reasons that leads to forced service interruption, particularly so with the outdoor type, hence the number of customer-owned outdoor substations does come to affect forced service interruption frequency.

(5) Transformers' Peak Load Rate

The higher peak load /capacity rate of main transformer in substation, the higher the fault probability.

(6) Geographical Condition

The probabilities of forced service interruption among various geographical conditions are different. In urban area, it was affected by numerous human factors, such as overhead circuit sometimes was touched by crane, or underground circuit may be broken by road construction, and then induced system interruption. In mountainous area, the probability of system interruption is increased because of

lighting and wind. In urban area, the distance from crew's office to the location of fault may be short, but duration of service interruption can be long because of traffic jam. In mountainous area, the fault location may have a very long distance to crew's office. Forced service interruption frequency in mountainous area tends to be long yet affects a smaller number of customers; whereas forced service interruption duration in urban area tends to be shorter but affects a larger number of customers.

(7) Radial Circuit Ratio

Radial lines have a higher probability of forced service interruption than a looped circuit line. If a fault occurs on a loop circuit, electricity generally can be supplied from the other end, and it will not cause service interruption. However, radial circuit surely provides higher probability of service interruption than Loop circuit, because of its lack of supporting power source.

(8) Customers' Ineffective Support

This factor is also especially addressed by Taipower's field engineers. Most transmission circuits are installed reclosing functions to avoid temporary interruption, but some industrial customers need to be notified before electricity restoration. Among these customers, some of them due to shortage of manpower, refuse or can't cooperate to re-energize load within 1 minute. It extends the duration of system interruption. The higher the level of customer cooperation, the more likely the forced service interruption duration can be shortened.

(9) Load Transfer Inability

When a fault is occurred and isolated, some customers may not be transferred to another circuit because the connected circuits lack of load transfer capacity. It means that the number of customers affected by system interruption is

increased. Factors which can affect the load transfer capability of circuits are:

- Geographical Conditions

Because load is centralized in urban area, circuits within the area generally supply heavy loads and are poor in load transfer ability.

- Radial Circuit Ratio

The load on radial circuit can't be transferred when fault is occurred because of no other circuits connected to it.

- Transformers' Peak Load Rate

High peak load /capacity rate of main transformer in substation reduces load transfer ability of transformer.

- Lack of Backup Capacity

Circuits don't conform to N-1 criteria generally inducing load transfer inability.

(10) Customer Density

Customer density of urban, suburban and mountainous areas are great different and naturally influence the number of customers affected by system interruption.

3.3 Design of Evaluation Indices

Only the evaluation index values corresponding to disparity factors which are positioned at the lowest layer of AHP sub-model need to be collected.

Each disparity factor at the lowest layer is corresponding to a well defined and collectable evaluation index value which can portray the regional characteristics and represent the disparity among the regional subsystems for transmission forced

interruption. Following paragraphs discuss the evaluation index that each disparity factors adopted for calculation of evaluation target.

(1) Weather Environments

According to Taipower's record, the major factors for the occurrence of forced transmission system interruption caused by severe weather include thunderbolt, salt and fog. Typhoon generally causes serious system interruption in Taiwan, but as mentioned in Chapter 2, the major event will be excluded in the statistics of SAIDI metric value within the same utility. The number of power service interruption times caused by thunderbolt, salt or fog with occurrence at regional transmission system in base year will be counted.

(2) Overhead /Underground Circuit Ratio

The corresponding index values are calculated by the percentage of overhead and underground feeders in circuit length out of the total circuit length respectively to describe the high probability of service interruption occurred on overhead circuit and the long duration of service interruption occurred on underground circuit.

(3) Total Circuit Length

This index value is calculated by the total circuit length in kilometers.

(4) Customer's Outdoor Substations

This index value is calculated by the number of outdoor substations owned by customers.

(5) Transformers' Peak Load Rate

This index value is calculated by the annual peak load divided by the total capacity of transmission substations' main transformers.

(6) Geographical Condition

This index value includes calculation of kilometer squares for urban, suburban and mountainous areas within the region respectively, because the probabilities of forced interruption of urban, suburban and mountainous areas are different for the same size of area. This index values also refer to the percentage for urban, suburban and mountainous regions in areas out of the total areas governed by transmission regional office, respectively, because the customer density of above three kinds of areas are different too.

(7) Radial Circuit Ratio

This index value is calculated by the radial circuit percentage in circuit length out of the total circuit length.

(8) Customers' Ineffective Support

Number of customers that cannot cooperate with the transmission regional office for efficient power restoration, refer mainly to the customers who refuse the trial re-energization of transmission lines for power restoration within a certain duration (e.g. 1 minute), due to manpower shortage.

(9) Lack of Backup Capacity

The index value refers to the number of circuits that do not meet (N-1) criterion.

(10) Customer Density

The index values refer to the percentage for urban, suburban and mountainous regions in areas out of the total areas governed by transmission regional office, respectively. They reflect the impact on average customers affected by system interruption from different customer density of urban, suburban and mountainous areas.

The above disparity factors and their corresponding evaluation indices are

summarized in Table 3.1.

Table 3.1 Evaluation Index Designed to Measure Regional Status on Disparity Factors of SAIDI for Transmission Forced Service Interruption

Disparity Factors	Evaluation Index
Geographical conditions	Kilometer squares or percentage for urban, suburban and mountainous areas
Weather environments	The number of power service interruption times caused by thunderbolt, salt or fog with occurrence at regional transmission system
Total circuit length	The total circuit length in kilometers
Overhead/underground circuit ratio	The percentage of overhead and underground feeders in circuit length out of the total circuit length respectively
Radial circuit ratio	The radial circuit percentage in circuit length out of the total circuit length
Transformers' peak load rate	The annual peak load divided by the total capacity of transmission substations' main transformers
Lack of backup capability	Number of circuits that do not meet (N-1) criterion
Customer's outdoor substation	The number of outdoor substations owned by customers
Customers' ineffective support	Number of customers that cannot cooperate with the transmission utility for efficient power restoration , referring mainly to the customers who refuse the trial re-energization of transmission feeders for power restoration, due to manpower shortage

3.4 Questionnaire Design

The questionnaire design is tends to acquire the experience of professionals and field engineers by their answering of the questions. Three sets of questionnaire were designed according to the evaluation target structure of Figs. 3.1~3.3. Six survey meetings have been conducted each at one of Taipower's 6 transmission regional

offices. Fifteen experienced engineers who are either the section chief or the department head of the operation or maintenance department in the same transmission regional office were surveyed. Thus total 90 engineers have been surveyed for the transmission forced service interruption. These respondents evaluated the relative weight of disparity factors which were enlisted in Figs. 3.1~3.3 on basis of their field experiences.

To assist the respondent to logically answer the questions in the questionnaire, the same questions, for evaluating the factors at the same layer, were asked three times in different forms, i.e.,

- (1) the level of importance for each factor (e.g., extremely important, very important etc.),
- (2) the priority order according to their importance, and
- (3) the pairwise comparison of factors.

Refer to Appendix enlists these three forms of questions designed in the questionnaire conducted for the SAIDI evaluation of transmission forced service interruption. The first question format is designed to assist the respondents compiling their judgment on the degree of impact to the evaluation target for each disparity factor. Then the respondents enter the second stage of questions which force them to rank the disparity factors into a priority order. The results of the priority order then help the respondent cross-check with the first-stage results. If there is conflict between these two stages of results, the respondent then have to go back to revise his answers. The third question proceeds with a pairwise comparison of factors after the respondent confirmed his judgment of importance for each factor through answering the first and second stages of questions. Pairwise comparison can further clarify the decision of respondents on their ranking of the relative importance of disparity factors.

As presented in Chapter 2, the AHP provide tools to identify the inconsistency of the pairwise comparison results so that the respondent, through an iterative revision process of his or her judgment, can finally reach a more consistent pairwise comparison results. The numerical results shall be presented in Chapter 5.

