

CHAPTER 1

INTRODUCTIN

1.1 Background

In general and classic, “reliability” is “the probability of a device or system performing its function adequately, for the period of time intended, under the operating conditions intended.” For electric power system, reliability means providing the users with continuous service of satisfactory quality [1].

Power system reliability is measured by reliability indices. As well known, electric power system is composed of generation, transmission and distribution systems. These systems use different reliability indices on their respective applications. That is why whenever the generation system is talked about; we pay much attention to Availability Factor (AF). When transmission system is discussed, System Minutes (SM) shows its importance. For distribution system, average interruption frequency and duration is always mentioned.

For generation system, according to IEEE Std. 762-2006, performance index (e.g. AF) of generating unit is calculated from the areas of Fig. 1.1 and the definition of these performance indices are listed in Table 1.1 [2].

For transmission system, the International Transmission Operations and Maintenance Study (ITOMS), a consortium of international transmission companies, adopts System Minutes (SM) and Circuit Availability (AR) to evaluate reliability of transmission system [3]. The definitions are as follows:

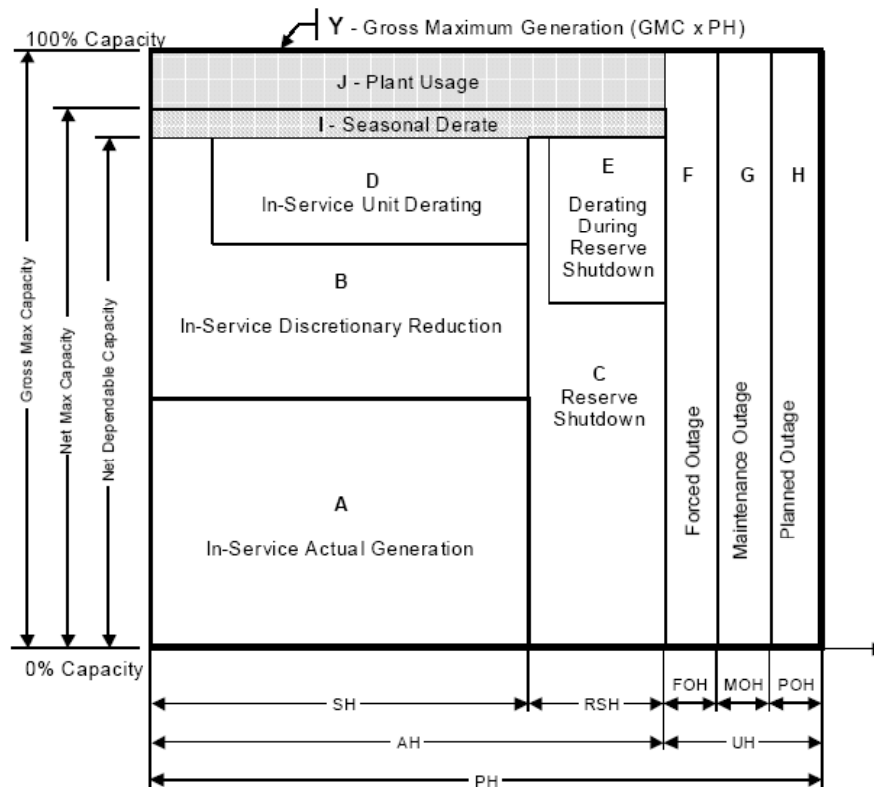


Fig. 1.1 Area for categories of capacity versus period hours [2]

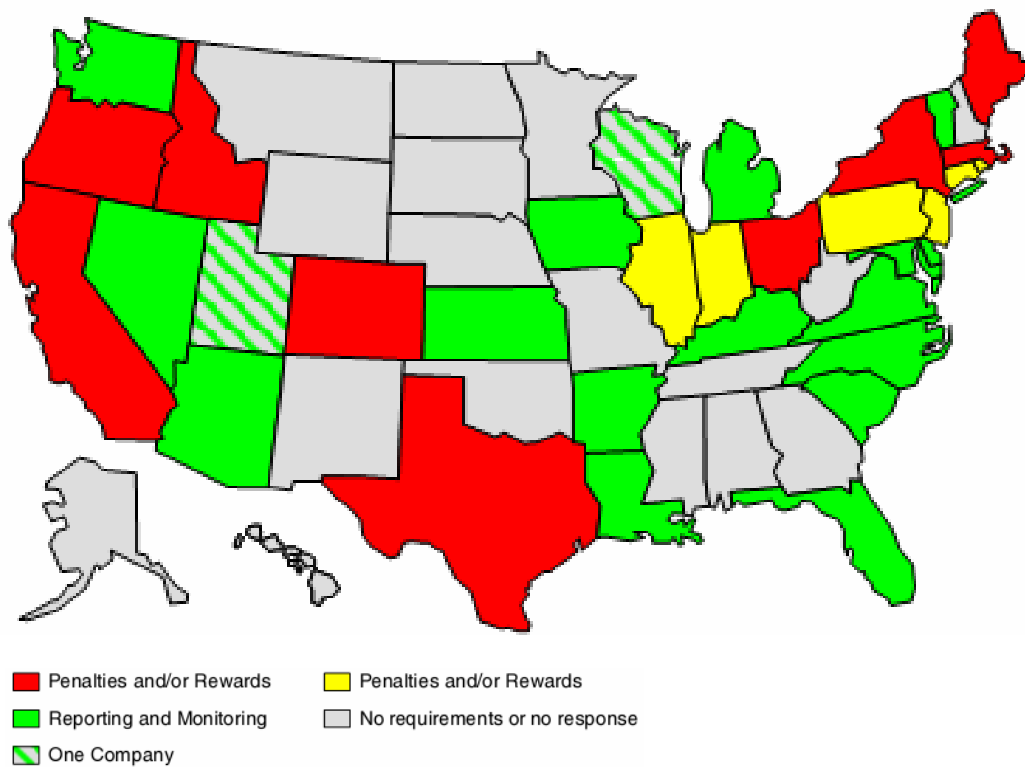


Fig. 1.2 Reliability reporting requirements in the United States as of 2001 [5]

Table 1.1 Performance Indices Defined in IEEE Std. 762-2006

Performance Index		Formula
Abbr.	Name	
<i>AF</i>	Availability Factor	$AF = \frac{A+B+C+D+E+I}{Y} \times 100\%$
<i>UF</i>	Unavailability Factor	$UF = FOF + MOF + POF$ $= \frac{F+G+H}{Y} \times 100\%$
<i>EAF</i>	Equivalent Availability Factor	$EAF = \frac{A+B+C}{Y} \times 100\%$
<i>EUF</i>	Equivalent Unavailability Factor	$EUF = \frac{D+E+F+G+H}{Y} \times 100\%$
<i>FOF</i>	Forced Outage Factor	$FOF = \frac{F}{Y} \times 100\%$
<i>MOF</i>	Maintenance Outage Factor	$MOF = \frac{G}{Y} \times 100\%$
<i>UOF</i>	Unplanned Outage Factor	$UOF = \frac{F+G}{Y} \times 100\%$
<i>POF</i>	Planned Outage Factor	$POF = \frac{H}{Y} \times 100\%$
<i>SF</i>	Service Factor	$SF = \frac{SH}{PH} \times 100\%$ $= \frac{A+B+D}{Y} \times 100\%$
<i>SDF</i>	Seasonal Derating Factor	$SDF = \frac{I}{Y} \times 100\%$
<i>UDF</i>	Unit Derating Factor	$UDF = \frac{D+E}{Y} \times 100\%$
<i>GCF</i>	Gross Capacity Factor	$GCF = \frac{A+J}{Y} \times 100\%$
<i>NCF</i>	Net Capacity Factor	$NCF = \frac{A}{Y} \times 100\%$

註：1. $EAF = AF - (UDF + SDF)$

2. $EUF = UF + UDF$

3. $AF + UF = 100\%$

4. $EAF + EUF + SDF = 100\%$

5. $UF = POF + UOF$

6. $EUF = POF + UOF + UDF$

7. $SDF + EAF + POF + UOF = 100\%$

(1) System Minutes

$$SM = 60 \times \frac{\text{Unserved Energy (MWh)}}{\text{System Peak Load (MW)}} \quad (1-1)$$

(2) Circuit Availability

$$CA\% = \frac{\text{Sum of Available Hours of Circuits}}{\text{Total Number of Circuits} \times 8760} \times 100 \quad (1-2)$$

For distribution system, according to IEEE Std 1366-2003, the electric power distribution reliability indices include 7 kinds of sustained interruption, 2 kinds of load based interruption and 3 kinds of momentary interruption which are listed in Table 1.2~1.4 [4].

Under the global trend of deregulation of electricity industry, introduction of competition in generation and transmission segments of power system could have a negative impact on system reliability received by ultimate customers. It causes regulatory agencies pay more and more attention to the reliability performance issues.

In U.S., 11 states reward or penalize utilities based on reliability performance, 16 states require annual reliability reporting and 5 states are considering some form of reporting requirements. A map of U.S. state reporting requirements as of 2001 is shown in Fig. 1.2 [5].

The reliability rules or standards created by regulatory agencies generally include: (1) metrics, (2) reliability targets for minimum level and objective level, (3) major events included/exclude and (4) rewards and penalties [6]. Because the reliability performance of a power system is announced to the public indicated by reliability metrics, accordingly, a rational comparison of power system reliability performances

among regions within a utility or among utilities by reliability indices obviously reveals its importance.

Table 1.2 Distribution Reliability Indices for Sustained Interruptions

Abbr	Name	Description	Formula
SAIFI	System Average Interruption Frequency Index	$\frac{\sum \text{Total Number of Customers Interrupted}}{\text{Total Number of Customers Served}}$	$\frac{\sum N_i}{N_T}$
SAIDI	System Average Interruption Duration Index	$\frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Served}}$	$\frac{\sum r_i N_i}{N_T}$
CAIDI	Customer Average Interruption Duration Index	$\frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Interrupted}}$	$\frac{\sum r_i N_i}{\sum N_i}$
CTAIDI	Customer Total Average Interruption Duration Index	$\frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Interrupted}}$	$\frac{\sum r_i N_i}{CN}$
CAIFI	Customer Average Interruption Frequency Index	$\frac{\sum \text{Total Number of Customers Interrupted}}{\text{Total Number of Customers Interrupted}}$	$\frac{\sum N_i}{CN}$
ASAI	Average Service Availability Index	$\frac{\text{Customer Hours Service Availability}}{\text{Customer Hours Service Demands}}$	$\frac{N_T \times 8760 - \sum r_i N_i}{N_T \times 8760}$
CEMI _n	Customers Experiencing Multiple Interruptions	$\frac{\text{Total Number of Customers that Experience more than n Sustained Interruptions}}{\text{Total Number of Customers Served}}$	$\frac{CN_{(k>n)}}{N_T}$

Where

r_i = Restoration time for each interruption event.

N_i = Number of interrupted customers for each sustained interruption event.

N_T = Total number of customers served for the areas.

CN = Total number of customers who have experienced a sustained interruption.

$CN_{(k>n)}$ = Total number of customers who have experienced more than n sustained interruptions.

Table 1.3 Distribution Reliability Indices for Load based Interruptions

Abbr.	Name	Description	Formula
ASIFI	Average System Interruption Frequency Index	$\frac{\sum \text{Total Connected KVA of Load Interrupted}}{\text{Total Connected KVA Served}}$	$\frac{\sum L_i}{L_T}$
ASIDI	Average System Interruption Duration Index	$\frac{\sum \text{Connected KVA Duration of Load Interrupted}}{\text{Total Connected KVA Served}}$	$\frac{\sum r_i L_i}{L_T}$

Table 1.4 Distribution Reliability Indices for Momentary Interruptions

Abbr.	Name	Description	Formula
MAIFI	Momentary Average Interruption Frequency Index	$\frac{\sum \text{Total Number of Customer Momentary Interruptions}}{\text{Total Number of Customer Served}}$	$\frac{\sum IM_i N_{mi}}{N_T}$
MAIFI _E	Momentary Average Interruption Event Frequency Index	$\frac{\sum \text{Total Number of Customer Momentary Interruption Events}}{\text{Total Number of Customer Served}}$	$\frac{\sum IM_E N_{mi}}{N_T}$
CEMSMI _n	Customers Experiencing Multiple Sustained Interruption and Momentary Interruption Events	$\frac{\sum \text{Total Number of Customer Experiencing more than n Interruptions}}{\text{Total Number of Customer Served}}$	$\frac{CNT_{(k>n)}}{N_T}$

Where

IM_i = Number of momentary interruptions.

IM_E = Number of momentary interruption events.

N_{mi} = Number of Interrupted customers for each momentary interruption event.

$CNT_{(k>n)}$ = Total number of customers who have experienced more than n sustained interruptions and momentary interruption events.

1.2 Scope

The most widely used reliability indices are averages that treat every customer equally. Distribution reliability statistics, based on sustained interruptions, are usually the primary benchmark used by utilities and regulators to identify service quality and to measure performance.

Industry-standard reliability measures such as System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index (CAIDI) are the indices commonly adopted by electric utilities for benchmarking the reliability performance within and among the utilities. These reliability measures have limitations, however are normally considered good aggregate measures of reliability and are utilized as reliability standards for system reliability improvements. The survey of distribution reliability indices used by utilities in U.S. is shown in Fig. 1.3 and the metric values adopted by some regulatory agencies for power system reliability reporting is shown in Table 1.5 [5-10].

According to the definition,

$$CAIDI = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Interrupted}} = \frac{SAIDI}{SAIFI} \quad (1-3)$$

$$ASAI = \left[1 - \left\{ \frac{(SAIDI)}{(8760 \text{ hours per year})} \right\} \right] \times 100 \quad (1-4)$$

Table 1.5 Metrics Adopted by Regulatory Agencies

Regulatory Agency or Power Company	Metrics Adopted
New York State Public Service Commission	SAIFI, CAIDI
New Jersey Board of Public Utilities	SAIFI, CAIDI
Texas Public Utilities Commission	SAIDI, SAIFI
Illinois Commerce Commission	SAIFI, CAIDI, CAIFI
Regulatory Agency of Victoria State of Australia	SAIDI
Electric Power System Council of Japan	SAIDI, SAIFI
Korea Electric Power Company	SAIDI, SAIFI
Taiwan Power Company	SAIDI, SAIFI

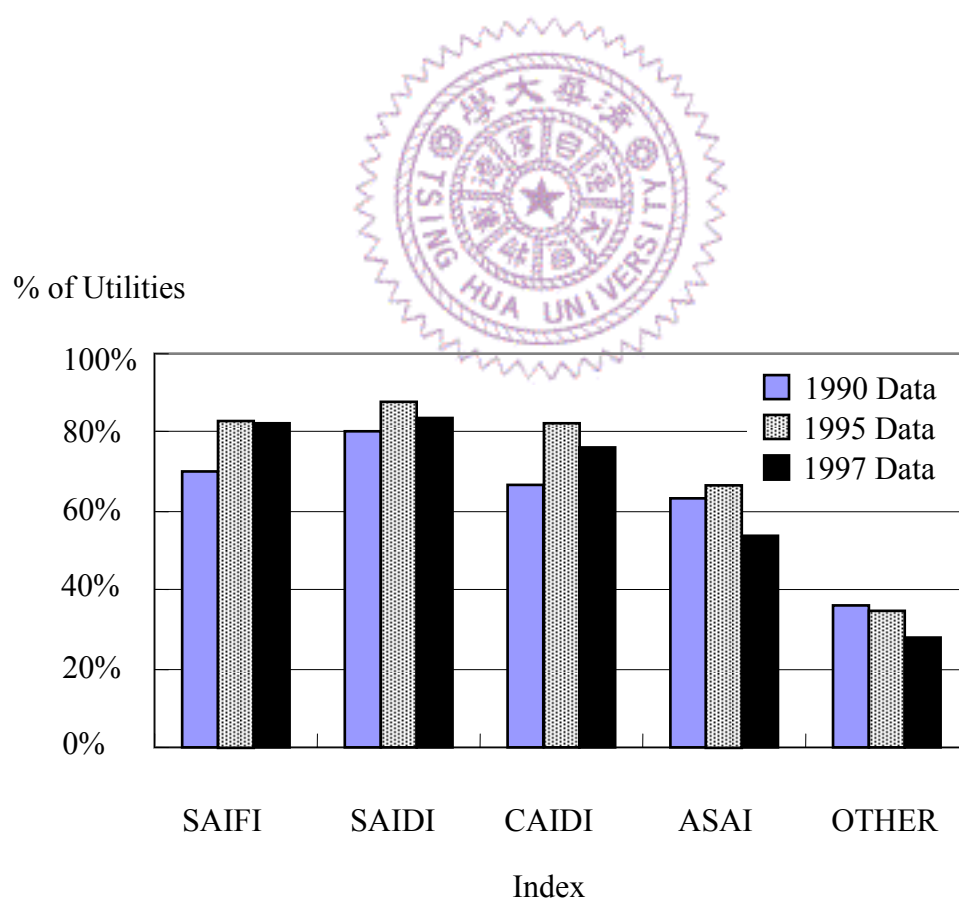


Fig. 1.3 Percentage of utilities use of an index of U.S.A. [10]

These two popular indices can also be expressed by SAIDI and SAIFI. Therefore, reliability indices SAIDI and SAIFI are focused in this dissertation.

If cross comparisons between regions or utilities are desirable, a number of issues and factors must be taken into considerations in establishing distribution reliability benchmarks. These factors which can greatly impact the accuracy, uniformity and consistency of reliability indices can be categorized into 4 major fields, i.e. definition and data classification, service territory, data collection process and system design [10].

Non-conformity of reliability index definitions can make it difficult to compare reliability performance among utilities, such as the minimum time length in definition of a sustained interruption which is listed in Table 1-6 [4, 8, 9, 11-13].

Major event such as that due to flood, earthquake, etc. could distort the major characteristic of a utility or the inherent feature of a database. Thus major events are commonly excluded during the process of future performance prediction. The definition for major events differ from utility to utility; nevertheless, in order to provide a common data base, according to IEEE Standard 1366-2003, 2.5 beta methodology has been proposed for identification of major events in perform SAIDI per day threshold calculation [14]. However in this dissertation, as the tested for numerical verification are the regions all in the same utility, the threshold of major event identification for all regions are the same and the influence of major events can thus be excluded, but major events effect still have to be considered, if the research includes the cross comparison among utilities.

Table 1.6 The Difference on Definition for a Sustained Interruption

Utility or Standard	Minimum Length for Sustained Interruption in Minutes
IEEE Std. 1366-2003	5
Canadian Utilities	1
Korea Electric Power Co.	5
Kansai Electric Power Co.	1
Kyushu Electric Power Co.	5
Taiwan Power Co.	1

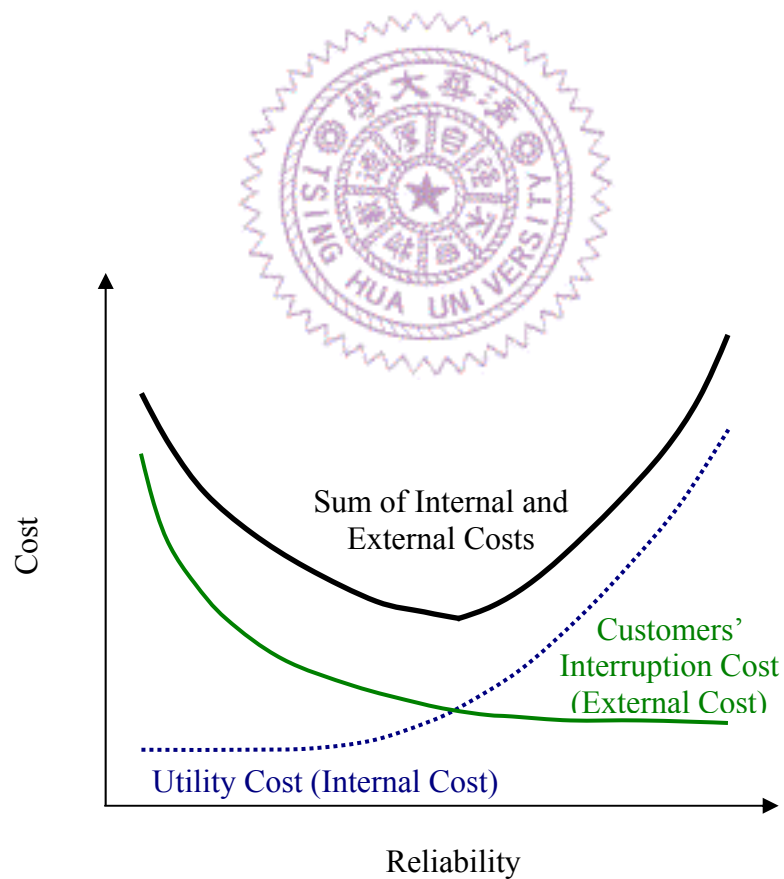


Fig. 1.4 Reliability cost and reliability worth curves [16]

In short, the scope of this dissertation is focused on evaluation of SAIDI and SAIFI levels of regional power systems, covering the transmission and distribution systems, as well as the forced and planned outages.

1.3 Literature Review

According to the definition of reliability in section 1.1, probability mathematics plays a prominent role in the theory of reliability, because in reliability prediction, the statement about events in the future can be made only in terms of the chances for the various alternative possibilities. A good orientation in the vast literature about this topic is listed in [15].

This kind of purpose and its measure, is proper to the reliability planning of forced outage, but unfortunately is not suitable for evaluation of reliability performance especially for planned outage. These probability techniques are also inappropriate when applied to benchmarking the reliability performance through reliability indices such as those of customer orientation, SAIDI, SAIFI, etc. [16-38].

Theoretically, the system reliability metric value should be maintained at the cross point of the total cost curve for the utility and the interruption cost curve for customers, which equivalent to the lowest point of the social cost curve, as shown in Fig. 1.4 [39]. However, such social cost curves can vary from utility to utility and even from region to region though of the same utility. Because of the varying inherent feature among regions for both their power systems and customers, in practice, the reliability level of the regional power systems are rarely maintained at the theoretical point.

In setting the regional reliability targets, such as setting the yearly SAIDI targets for 2008, within a power utility, the utility's corporate management board or the regulator commonly set the targets by extrapolating the historical data, such as by extrapolating the historical SAIDI records.

Limited researches have been done of setting reliability targets or benchmarking reliability across electric utilities or across the service regions of the same utility. Presently, most utilities or regulators still have to rely on historical records without effective evaluation of the utilities or regional offices of the same utility on their managerial effort and/or efficiency, in setting the performance targets, as no effective methods are existing which can segment the managerial effort and/or efficiency of the utilities or the regional offices from the remaining factors which combine together to have caused the utilities or regional reliability performance records [39]. Consequently, the target setting without segmentation and evaluation of the managerial effort and/or efficiency among utilities or service regions could thus lead to unfairness in the resulted penalties or rewards, particularly among the service regions (or the transmission/distribution offices) within the same utility. The lack of proper methodology to compare reliability performance cross utilities can also degrade the effectiveness of the effort paid by the regulatory agency in monitoring the reliability performance of utilities.

Since the benchmarking or comparison of reliability indices across utilities is difficult, some literature declared that comparing is a very tough issue, such as "...Since no two utilities are alike under the same regulatory jurisdiction, benchmarking is not possible between utilities..." and "...Current benchmarking methods have led to some false conclusions due to the fact that they don't take into

account the various factors that affect reliability and that differ from utility to utility. These factors are real and present some real challenges to those interested in developing some valid benchmarks...” etc. [40, 41]. It is true that no two utilities are alike, but the comparison among utilities is not impossible.

To overcome this difficulty, a new procedure based on the analytic hierarchy process (AHP) is designed in this dissertation, which accounts for the disparity among regions on a variety of factors including the geographic, load, circuit, customers, maintenance work and expansion budget conditions, by: (1) measuring the regional status of each factor, and (2) weighing the relative impact among factors on the regional SAIDI or SAIFI. The weight acquisition process of AHP, which is a mathematically well proven process, though partially subjective, has been tested successfully in our field study [42-44].

The new procedure can effectively segment any specified factors from the remaining of benchmarking data by accounting for each disparity factor and their effect on the reliability performances individually, and then combining all the individual factors after segmentation into one logical procedure for derivation of the target levels. Because the weighted impact of each disparity factor is evaluated individually, any disparity factors which have clearly distorted the benchmarking in setting regional performance targets can be segmented effectively from the evaluation.

1.4 Contributions

This dissertation presents a methodology to provide a rational comparison on the relative reliability performances among the jurisdictional regions of a power utility.

The presented method has been successfully implemented on Taipower's 6 transmission and 22 distribution offices for their reliability performance evaluations.

The contributions of this research can be summarized as follows:

- (1) All the major factors that affect the SAIDI and the SAIFI metric values are investigated. Among them, those being adequate for describing or for differentiating the differences of regional characteristics of Taipower system are presented which serve as the basis of model formulation to be presented in this thesis..
- (2) Indices are then proposed for measuring these influential factors or regional characteristics. The index design accounts for the availability of data source.
- (3) The Analytic Hierarchy Process (AHP) is adopted in this thesis for comparison on the reliability performance among the utility's transmission or distribution subsystems. The AHP makes use of survey on utility's engineers or other professionals to acquire the relative weights among the influential factors. In this thesis, questionnaires are designed for the survey which through three ways of asking the questions can assist the engineers or professionals surveyed to clarify the questions and to make up their mind.
- (4) The thesis presents a logical and systematic procedure to assist the rational evaluation on the relative performance of SAIDI and SAIFI among the utility regions which can be further extended to benchmarking the reliability performance among power utilities.
- (5) Based on the testing or application experience of Taipower, the effectiveness and

limitation of proposed method for reliability performance evaluation are presented, which can benefit the future application of proposed method on the reliability benchmark among utilities.

1.5 Outline

In Chapter 2, the overall design of our AHP application to the reliability performance evaluation is presented. Among the presented, the first part refer to the overall all procedure, the AHP hierarchic structure of model formulation, two types of model parameters, the questionnaire design and the influence of intensity scale adopted to interpret the results of questionnaire. In the second part, the calculation procedure for obtaining the relative weight of disparity factors is presented, which includes the comparison matrix converted from the questionnaire results by use of the intensity scale, the calculation of eigenvector and maximum eigenvalue, the consistency index and consistency ratio, the iteration procedure of revising judgments for assurance of inconsistency cases check etc. In the third part, a numerical example is provided to clarify the calculation of AHP.

In Chapter 3, the disparity factors which could influence the SAIDI metric values of the for transmission system forced interruption are presented. Then, the design of evaluation index corresponding to each disparity factor is described. Lastly, the design of questionnaires for the transmission system reliability evaluation is discussed.

In Chapter 4, the disparity factors which could influence the SAIDI metric values for the distribution system forced interruption are presented. Also, the disparity factors of SAIDI for the distribution system scheduled interruption are proposed.

Then, the design of evaluation indices corresponding to these disparity factors is described. Lastly, the design of questionnaires for the distribution system reliability evaluation is discussed.

In Chapter 5, the weight calculated for the disparity factors as well as the comparison of questionnaire results surveyed on regional transmission systems and the district distribution systems are investigated. Then, the comparison of evaluation index values rated among the regional transmission systems and among the district distribution systems are discussed. In the third part, the comparison of SAIDI targets and the performance records among the regional transmission offices and among the district distribution offices of Taipower for the year of 2003 are evaluated.

In Chapter 6, the concluding remarks drawn from the research and the limitation of proposed procedure and the recommendations for future research are provided.

Appendix gives a partial list of the questionnaires for evaluation of the disparity factors for the SAIDI of distribution scheduled service interruption.