A NEW APPROACH TO DYNAMIC CONTINGENCY SELECTION

Chung-Liang Chang **Yuan-Yih Hsu**

Department of Electrical Engineering
National Taiwan University
Taipei, Taiwan

ABSTRACT

Contingency selection is important for the security analysis of a large scale power system since it can reduce the required computational effort by ranking the various outage events according to their severities. Among the three aspects of power system security, i.e., transient security, dynamic security, and steady-state security, contingency selection for dynamic security assessment is of concern in this paper. The proposed method is to use an iterative method to compute the eigenvalues of the system under outage conditions. The initial values for the iterative procedure are the eigenvalues for the normal operating condition (base case eigenvalues). To reduce the computational burden, the eigenvalues of the system under outage conditions from the first iteration are employed for contingency ranking. From the results obtained from the study on Taiwan power system, it is concluded that contingency ranking using the eigenvalues from the first iteration is both accurate and efficient. It is also found that only the eigenvalues for the worst-damped mode must be considered in contingency ranking. To further improve the efficiency of the proposed method, results obtained from the first iteration of the fast decoupled load flow (FDLF) are also used to model the operating conditions after contingencies. Again, it is observed that satisfactory dynamic contingency selection can be achieved by using the first iteration of FDLF with much less computational effort than that required by full AC power flow. It is thus concluded that accurate dynamic contingency selection can be performed efficiently by first computing the operating conditions after contingencies using the first iteration of FDLF and then calculating the eigenvalues for the worst-damped mode by using the first iteration of eigenvalue computations.

Keywords: contingency selection, security analysis, dynamic security assessment

1. INTRODUCTION

To reduce the computational requirements in the security analysis of a large power system, numerous approaches to steady-state contingency selection have been developed in the past decade [1–10]. These works on steady-state contingency selection have been very successful in ranking the severities of various outage events according to steady-state line overloadings and bus voltage violations following a generator trip or a line outage. Computational burden associated with security analysis can thus be alleviated by performing full AC power flow on only those cases on top of the ranking lists.

In addition to steady-state security assessment, dynamic security and transient security assessments are also important security functions in an energy management system. Only dynamic security assessment will be discussed in this paper.

It has been observed that, in a longitudinal power system such as Taiwan power system, dynamic instability may take place on some occasions due to insufficient damping for the electromechanical mode [11–12]. Fast dynamic security assessment is thus essential for these cases where undamped low frequency oscillations may impose undesirable limitations on the operation of power systems. This motivates the development of an efficient approach for dynamic contingency selection which can reduce the computational effort in dynamic security assessment to a great extent.

In contrast to the significant advances in steady-state contingency selection, developments in dynamic contingency selection have been rather limited. Venikov et al. [13] estimated system stability using the results from load flow computations. The proposed method was effective only for steady-state stability since it failed to take system dynamics into account. For the purpose of dynamic contingency selection, the sensitivities of system eigenvalues to a contingency can be evaluated using left and right eigenvectors [14–16]. The major drawback of such an approach is that considerable effort is needed for eigenvector computations, which must be repeated any time the network topology or operating condition of the system is changed.

In this paper, a novel approach for dynamic contingency selection is developed. The proposed method, which can be regarded as an extension of the work by Albugh, et al. [1] on steady-state contingency selection to the dynamic case, utilizes the results from the first iteration of the fast decoupled load flow (FDLF) to estimate the operating condition following an outage event. Then, the eigenvalues from the first iteration of an iterative eigenvalue computation method are used to approximate system eigenvalues under outage conditions.

To demonstrate the effectiveness of the presented method, outage events on the transmission lines of Taiwan power system are studied. The results from this study indicate that accurate ranking list for dynamic security assessment can be achieved very efficiently by the proposed algorithm.

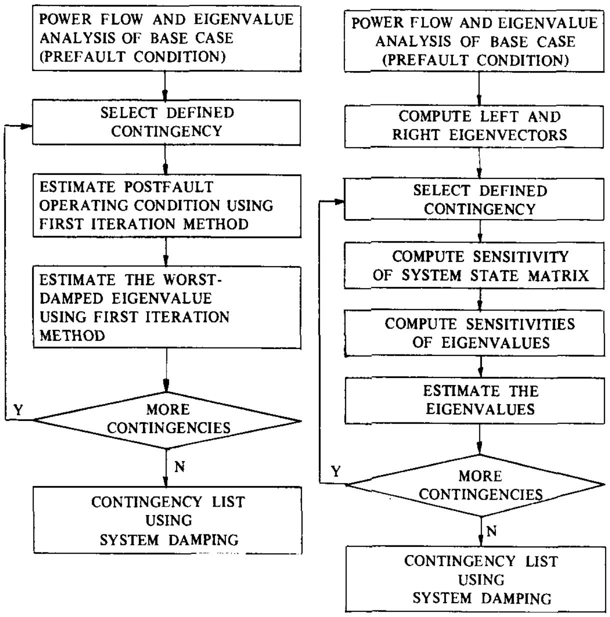
2. PROPOSED METHOD

Power system dynamic security assessment is aimed at examining the dynamic performance of the system following an outage. In general, two steps are involved for this purpose: the determination of postfault operating condition using load flow analysis and the computation of system eigenvalues following an outage event. This time-consuming process must be repeated for each possible outage event, thus making dynamic security analysis computationally infeasible for on-line use unless certain simplifying algorithm is adopted.

An efficient algorithm using the first iteration of FDLF has been presented for determining system operating conditions [1]. The method has been shown to be capable of alleviating the computational burden while maintaining good accuracy. In view of the success in approximating the operating condition by using the results from the first iteration, it is decided to extend this concept to estimate eigenvalues.

In this paper, an iterative algorithm based on modified AESOPS (Analysis of Essentially Spontaneous Oscillations in Power Systems) program [17] is employed to calculate the eigenvalues for low frequency electromechanical mode oscillations. It is noted that only the electromechanical mode oscillations are considered in dynamic contingency selection since a longitudinal power system such as Taiwan power system is vulnerable to these oscillations when the trunk lines connecting the various areas of the system are heavily loaded. In fact, as will be shown later, the damping of the worst-damped electromechanical mode will be employed as the performance index for dynamic contingency selection. Thus, the proposed algorithm is very efficient since only the first iteration has to be performed for only one oscillation mode. It will also be shown later that the algorithm can yield very accurate contingency ranking lists.

In summary, the proposed method employs the first iteration of FDLF to determine system operating condition and then uses the first iteration of AESOPS to estimate worst-damped eigenvalues. It can be regarded as the "first-iteration method for dynamic contingency selection". Fig. 1 illustrates the flow charts of both the proposed first-iteration method and the sensitivity method [14–16] for purpose of comparison.



(A) PROPOSED FIRST-ITERATION METHOD

(B) SENSITIVITY METHOD

Fig. 1 A comparison of the proposed first-iteration method and the sensitivity method

3. DESCRIPTION OF THE STUDY SYSTEM

The system studied is the Taiwan power system which consists of 16 generating units including 2 synchronous condensers as shown in Fig. 2. These generating units are geographically located at three different areas on the island of Taiwan, i.e. the northern area, the central area, and the southern area. Under normal operating condition (called base case), the generator bus data and the area generations and load demands are listed in Tables 1 and 2, respectively. The fifteen electromechanical oscillation modes of the system are listed in Table 3, where the blocked entries correspond to those generators with the normalized speeds greater than 0.15. It can be observed from Table 3 that the damping for the oscillation mode with lowest frequency (1.181 Hz) is very poor. This is due to the longitudinal structure of Taiwan power system and the great amount of power flows on the EHV transmission lines (see Table 1 and Table 2). Hence, it is important to examine how the damping for this worst-damped oscillation mode changes as a result of an outage event on one of the 345 trunk lines connecting the three areas of the system. In fact, it is the main objective of this paper to establish a dynamic contingency ranking list according to the estimated damping for the worst-damped mode from first iteration results. When the ranking list is established, detailed dynamic stability analyses and eigenvalue computations should be performed on only those outage events on top of the list.

Table 1. Summary of generator bus data

bus number	bus name	type	area	real power	reactive power	voltage magnitude	voltage angle
3	First Nuclear plant #1	nuclear	N	582.0	95.0	0.9900	17.0
4	First Nuclear plant #2	nuclear	N	587.0	95.6	0.9900	17.0
9	Second Nuclear plant #1	nuclear	N	950.0	148.3	0.9900	17.4
10	Second Nuclear plant #2	nuclear	N	853.0	137.0	0.9900	16.7
25	Shenao #1	thermal	N	38.0	26.8	0.9900	10.1
27	Shenao #2	thermal	N	85.0	72.1	0.9900	9.8
100	Taipei (synchronous condensers)	S.C.	N	0.0	-20.0	0.9993	4.4
112	Chinshan	hydro	C	74.1	40.6	0.9900	0.0
116	Churkung	hydro	C	22.0	10.0	0.9701	-9.3
118	Takuan	hydro	C	33.0	50.0	0.9892	-10.8
219	Talin #1	thermal	S	112.0	118.3	0.9900	-13.1
237	Hsinta #1	thermal	S	220.0	115.8	0.9900	-7.3
238	Hsinta #2	thermal	S	220.0	115.4	0.9900	-7.3
257	Nanpu #1 & 2	thermal	S	40.0	29.9	0.9900	-15.4
258	Nanpu #3	thermal	S	57.0	39.1	0.9900	-15.3
300	Kaohsung	S.C.	S	0.0	-33.0	0.9976	-18.6

Table 2. Real power generations and load demands in the three areas

area	real power generation (MW)	real power generation (%)	load demand (MW)	load demand ((%))
North (N)	3095	80%	1400	37%
Center (S)	129.1	3.3%	940	24.8%
South (S)	649	16.7%	1450	38.2%
Total	3873.1	100%	3790	100%

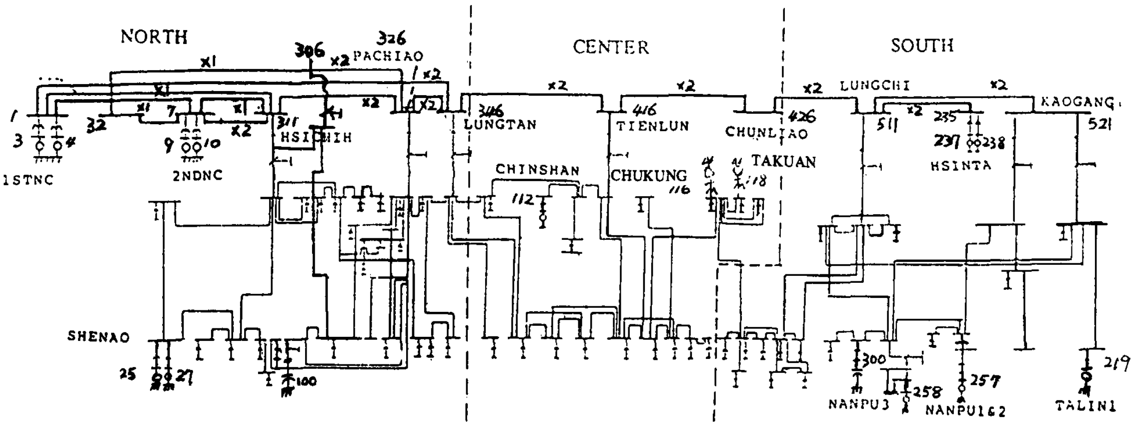


Fig. 2 One-line diagram of Taiwan power system

Table 3. Electromechanical oscillation modes for the base case

mode number	frequency (Hz)	eigenvalue $\alpha\pm\beta$	driven generator	normalized speed eigenvectors															
				bus 3	4	9	10	25	27	100	112	116	118	219	237	238	257	258	300
1	1.181	-0.0638±j7.4191	#9	0.12 -0.04	0.12 -0.04	0.58 0.02	0.52 -0.02	0.00 0.00	0.02 -0.01	0.00 0.00	-0.08 0.03	-0.03 0.00	-0.08 0.00	-0.59 -0.02	-1.00 -0.01	-1.00 -0.01	-0.20 -0.01	-0.21 0.00	-0.03 0.02
2	1.350	-3.7616±j8.4815	#100	-0.07 0.02	-0.07 0.02	-0.17 -0.06	-0.17 -0.05	0.00 0.01	-0.03 0.02	1.00 -0.01	-0.02 0.00	0.00 0.00	-0.01 0.01	-0.03 0.00	-0.05 0.00	-0.05 0.00	-0.01 0.00	-0.01 0.00	-0.01 -0.01
3	1.388	-3.2923±j8.7223	#300	0.00 -0.02	0.00 -0.02	0.06 -0.07	0.05 -0.06	0.00 0.00	-0.01 0.00	0.00 0.00	-0.03 -0.02	-0.01 0.01	-0.02 0.02	-0.14 0.11	-0.24 0.06	-0.24 0.06	-0.05 0.05	-0.02 0.14	1.00 0.05
4	1.499	-1.4852±j9.4176	#112	-0.04 0.04	-0.04 0.04	-0.12 -0.11	-0.13 -0.08	0.00 0.00	-0.01 0.02	0.00 0.00	1.00 -0.01	0.01 0.01	0.02 0.03	-0.10 0.03	-0.19 0.03	-0.19 0.03	-0.03 0.01	-0.03 0.02	0.00 0.01
5	1.534	-0.3441±j9.6400	#10	0.01 -0.01	0.01 -0.01	-1.00 0.00	1.00 0.00	0.01 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	-0.01 0.00	-0.01 0.00	0.00 0.00	0.00 0.00	0.00 0.00
6	1.673	-0.3493±j10.5105	#4	0.84 -0.13	0.84 -0.14	-0.92 -0.02	-1.00 0.00	0.03 0.01	0.49 0.41	0.00 0.00	-0.02 -0.04	0.01 0.00	0.02 -0.01	-0.05 0.01	-0.11 0.00	-0.11 0.00	-0.01 0.00	-0.01 0.00	0.00 0.00
7	1.717	-0.2542±j10.7894	#27	-0.65 -0.17	-0.66 -0.17	0.27 0.29	0.27 0.31	0.03 -0.02	0.91 -0.42	0.00 0.00	-0.01 0.02	0.00 0.00	-0.01 -0.01	0.02 0.01	0.01 0.05	0.01 0.05	0.00 0.00	0.00 0.00	0.00 0.00
8	1.791	-0.1562±j11.2513	#219	0.03 0.01	0.03 0.01	0.02 -0.01	0.01 -0.01	0.00 0.00	0.03 0.00	0.00 0.00	0.01 0.00	0.00 -0.01	0.02 -0.03	1.00 0.02	0.61 0.01	0.61 0.01	0.21 -0.01	0.17 -0.02	0.00 -0.01
9	1.824	-0.4937±j11.4603	#3	1.00 0.00	-0.99 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00
10	1.859	-0.1829±j11.6828	#237	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	1.00 0.00	-1.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00
11	1.866	-2.1951±j11.7260	#116	-0.05 -0.02	-0.05 -0.02	0.00 -0.05	-0.01 -0.05	0.00 0.00	-0.03 0.00	0.00 0.00	-0.05 -0.06	1.00 -0.04	0.01 0.55	-0.16 -0.01	-0.15 -0.09	-0.15 -0.09	-0.06 0.01	-0.06 0.03	0.01 0.00
12	1.929	-1.5848±j12.1176	#118	-0.05 0.01	-0.05 0.01	-0.02 -0.02	-0.03 -0.02	0.00 0.00	-0.03 0.02	0.00 0.00	-0.06 -0.02	0.00 -0.23	1.00 0.01	-0.14 0.07	-0.15 0.00	-0.15 0.00	-0.05 0.00	-0.02 0.07	0.00 0.00
13	1.938	-0.1656±j12.1784	#257	0.00 0.00	0.01 0.00	0.01 0.00	0.01 0.00	0.00 0.00	-0.01 0.00	0.00 0.00	0.00 0.00	0.00 -0.01	0.00 -0.03	-0.80 0.05	-0.15 -0.01	-0.15 -0.01	1.00 0.04	0.24 -0.02	0.00 -0.01
14	2.043	-0.2720±j12.8381	#258	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	0.00 0.00	-0.01 0.00	0.00 -0.01	-0.01 -0.03	-0.34 0.02	-0.11 -0.01	-0.11 -0.01	-0.33 0.04	1.00 0.02	0.00 -0.02
15	2.989	-0.3420±j18.7802	#25	-0.11 0.00	-0.11 0.00	-0.16 0.00	-0.17 0.00	1.00 0.00	-0.19 0.00	0.00 0.00	-0.02 -0.01	0.00 0.00	-0.01 0.00	-0.02 0.00	-0.04 0.00	-0.04 0.00	-0.01 0.00	-0.01 0.00	0.00 0.00

4. RESULTS

Using the normal operating condition (base case solution) as the initial guess, the first iteration of fast decoupled load flow is performed to estimate the operating condition after a line outage event. Then the first iteration of AESOPS is used to estimate the damping of the worst-damped electromechanical mode under each operating condition. Again, base case eigenvalues are chosen as the initial guess for the AESOPS. It is not necessary to compute all eigenvalues since only mode 1, the worst-damped electromechanical oscillation mode, is of major concern. To excite mode 1, generator #9 (see Table 3) is chosen as the driven generator.

In the following discussions, dynamic contingency selection will be performed for single-line-fault contingencies and double-line-fault contingencies on the 345 KV trunk lines.

4.1 Single-line-fault contingency ranking

The real parts of the eigenvalues associated with the worst-damped mode (α_0) and the oscillation frequencies ($\beta_0/2\pi$) for the system under various single-line-fault outages are listed in Tables 4 and 5. Table 4 gives the results from the exact method (full AC load flow and exact eigenvalue computations) while Table 5 lists the results from the proposed first-iteration method (first iteration of FDLF and first iteration of AESOPS).

Table 4. Single-line-fault contingency evaluation using the exact method

ranking	outaged branch	real part of mode 1 (α_0)	frequency ($\beta_0/2\pi$)
1	426–511	–0.0062	1.086
2	346–416	–0.0196	1.113
3	416–426	–0.0474	1.150
4	1–346	–0.0539	1.167
5	326–346	–0.0575	1.171
6	511–521	–0.0582	1.177
7	511–235	–0.0585	1.170
8	1–7	–0.0615	1.179
9	311–326	–0.0616	1.178
10	32–306	–0.0622	1.179
11	306–326	–0.0625	1.179
12	7–311	–0.0632	1.180
13	32–7	–0.0632	1.180
14	1–311	–0.0637	1.181

Table 5. Single-line-fault contingency evaluation using the first-iteration method

ranking	outaged branch	real part of mode 1 (α_0)	frequency ($\beta_0/2\pi$)
1	426–511	−0.1115 (mode 5)	1.258
2	346–416	−0.0327	1.120
3	416–426	−0.0495	1.151
4	1–346	−0.0556	1.168
5	326–346	−0.0584	1.172
6	511–521	−0.0596	1.178
7	511–235	−0.0600	1.172
8	1–7	−0.0616	1.179
9	311–326	−0.0619	1.178
10	32–306	−0.0628	1.179
11	306–326	−0.0631	1.179
12	7–311	−0.0632	1.180
13	32–7	−0.0633	1.180
14	1–311	−0.0637	1.181

By comparing the results in Tables 4 and 5, it is concluded that the first-iteration method can yield the same ranking list as that achieved by the exact method. But the first-iteration method requires much less computational effort. It is worth noting that the eigenvalues for mode 1 under the severest outage case (an outage on branch 426-511) can not be found by the first-iteration method. Instead, the eigenvalues for another mode (mode 5) are obtained. Previous experience revealed that, under such circumstances, the outage would be severer than other cases in which the eigenvalues for mode 1 can be figured out by the first-iteration method.

4.2 Double-line-fault contingency ranking

The results of contingency ranking for double-line-faults are compared in Table 6 and Table 7.

Table 6. Double-line-fault contingency evaluation using the exact method

ranking	outaged branch	real part of mode 1 (α_0)	frequency ($\beta_0/2\pi$)
1	511–235	islanding	
2	346–416	divergent	
3	416–426	divergent	
4	426–511	divergent	
5	1–346	−0.0332	1.138
6	511–521	−0.0359	1.163
7	326–346	−0.0402	1.144
8	311–326	−0.0556	1.170
9	32–306	−0.0577	1.172
10	32–7	−0.0581	1.173
11	306–326	−0.0593	1.175
12	7–311	−0.0607	1.177

Table 7. Double-line-fault contingency evaluation using the first-iteration method

ranking	outaged branch	real part of mode 1 (α_0)	frequency ($\beta_0/2\pi$)
1	511–235	islanding	
2	346–416	−0.1528 (mode 5)	1.318
3	416–426	−0.1643 (mode 5)	1.328
4	426–511	−0.1659 (mode 5)	1.328
5	1–346	−0.0381	1.141
6	326–346	−0.0460	1.149
7	511–521	−0.0511	1.177
8	311–326	−0.0566	1.170
9	32–306	−0.0586	1.173
10	32–7	−0.0587	1.173
11	306–326	−0.0603	1.175
12	7–311	−0.0632	1.180

Again, it is observed that there is only slight difference between the ranking lists in Table 6 and Table 7. This confirms the assertion that accurate contingency ranking can be achieved by the first-iteration method with much less computational effort. It is also noted that, in the first iteration method, the eigenvalues for mode 1 can not be found for those outage cases which cause islanding or divergent power flows. Of course, these cases are ranked as the severest among the outage events studied.

One may wonder how the eigenvalues associated with other modes than mode 1 would drift from their base case values when an outage takes place. To this end, Fig. 3 illustrates the most dominant eigenvalues for electromechanical modes for both the normal operating condition and the outaged conditions. It is observed that only mode 1 is critical for dynamic stability considerations. Thus, the eigenvalues for other modes need not be computed.

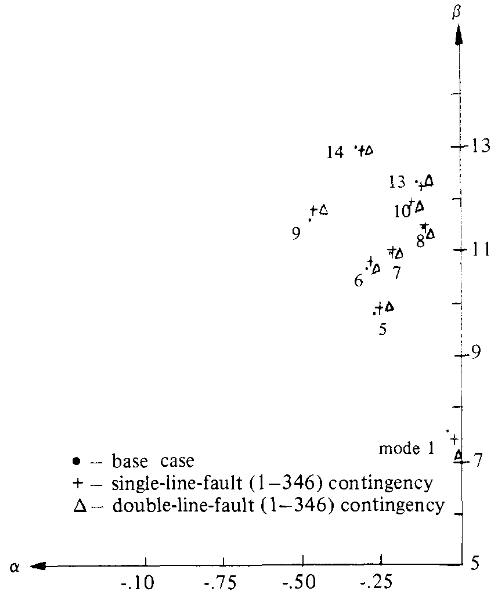


Fig. 3 Effect of line outage on electromechanical mode eigenvalues

5. CONCLUSIONS

A novel approach using the first iteration of FDLF and the first iteration of AESOPS has been proposed for dynamic contingency selection. It is found that accurate ranking list can be achieved very efficiently by using the developed first-iteration method. The computational burden incurred in dynamic security assessment can thus be alleviated since only those cases on top of the ranking list require detailed dynamic stability analyses. It is expected that further developments in this respect can lead to the possible implementation of on-line dynamic contingency ranking and security assessment packages on an energy management system in the near future.

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Yuan-Yih Hsu was born in Taiwan on June 19, 1955. He received his B.Sc., M.Sc., and Ph.D. degrees, all in electrical engineering, from National Taiwan University, Taipei, Taiwan.

From 1982 till 1983, he worked at the university of Calgary, Alberta, Canada, as a postdoctoral research fellow and instructor. Since 1984, he has been an associate professor at the Department of Electrical Engineering, National Taiwan University. At present, his research interests include power system dynamics, control and stability analysis, power system reliability analysis, short-term load forecasting, economic operation, and the application of computer methods to power system problems.

He is a member of IEEE.

Chung-Liang Chang was born in Taiwan on Feburary 16, 1958. He received his B.S. and M.S. degrees in electrical engineering from National Tsing Hua University, Hsinchu, Taiwan, in 1980 and 1982, respectively.

Since joining Taiwan Power Company in 1982, Mr. Chang has been working with the System Planning Department. From June, 1983 to March, 1987 he also taught at the Taiwan Power Company's Training Center. Since 1987, with the recommendation of Taiwan Power Company and the support of National Science Council of R.O.C., he has been working toward his Ph.D. degree in the Electrical Engineering Department of National Taiwan University, Taipei, Taiwan.