講 演

日本에 있어서의 電力系統工學 硏究

(Present Status of Power Sustem Research in Japan)

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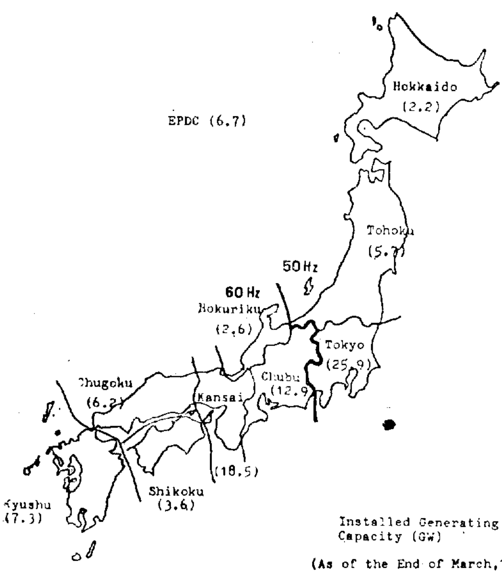
Ⅰ. RESEARCH ORGANIZATIONS

Power systems research in Japan is carried out by universities, power utilities, CRIEPI (Central



Power Utilities in Japan

Figure 1.

Research Institute of Electric Power Industry) and manufacturers.

Ten power utilities in Japan (see Figure 1) have their own research laboratories and they financially support CRIEPI. Research activities of 10 power utilities and CRIEPI are well coordinated by Central Electric Power Council (CEPC), a coodinating organization of 10 power utilities. No coordinating organization exists for manufacturers and universities.

Annual expenditures for research, the numbers of researchers and the numbers of research subjects in various organizations are summarized in Table 1.

Research in universities is mainly supported financially by individual university budgets and Research Fund for Scientific Research of Ministry of Educatio.

In addition to the research organizations mentioned above, there are a few organizations playing an important role in power systems research. One is Ministry of International Trade and Industry (MITI), which studies a problem of vital significance to the country in the far future under the cooperation of top experts from universities, power utilities, CRIEPI and manufacturers. Research subjects studied by MITI for the past several years

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Table 1. Rough Scale of Research Activity*

	Anual Expenditures**		No. of Researchers		No. of Research Subjects	
	Total***	Power System	Total	Power System	Total	Power System
	Million Dollars					
Universities	N.A.	0.1～0.17	140	50	110	40
CEIEPI	2****	0.15****	200	30	300	40
Power Utilities	32～35	2.5～3	700	120	1,200	64
Manufacturers	60	2～2.5	4,000	300	500	30

* Excluding nuclear generation and environmental researches
** Excluding personnel expenditures, US$=200 Yen
*** Including the construction cost for test apparatus
**** Excluding installation cost for large scale experimental facilities

include superconducting and cryogenic transmission system, future role of DC transmission technology etc. The current subject is the under sea and underground bulk power transmission system. Another important organization is Electric Cooperative Research Association (ECRA), which is financially supported by power utilities and electric manufacturers. It organizes study committees on problems of common interest to power utilities and/or manufacturers. Its recent activity includes "Research on Power System Stability Practical Method of Analyais, Stability Difficulties in Present and Future Power Systems in Japan and Practical Means to Improve Stability", "Power System Security", "Reliability Improvement of Protective Relaying System" etc. Research activity of ECRA is maintained by experts from universities, research institutions, power utilities and manufacturers.

II. RESEARCH ACTIVITIES

Data Source

To prepare this manuscript, the author has collected data on research activities in various research organizations. Data from power utilities have been collected through Central Electric Power Council, which surveys every year the research activities in power industry. As for the manufacturers and univerities, the author has chosen 6 major manufacturers and 13 universities, which are active in power systems field, and asked them to report their current research activities as extensively and accurately as their circumstances allow.

In spite of the above circumstances, it is needless to say that only the author is responsible for the statement and evaluation of research activity described in this manuscript.

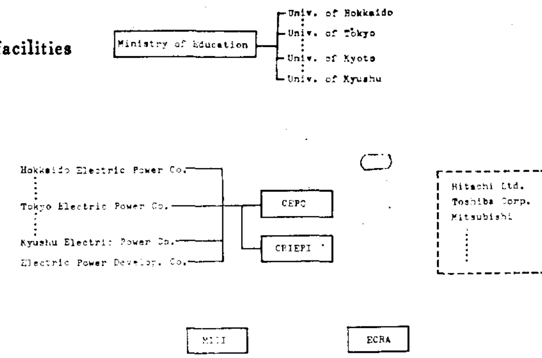

Figure 2. Research Organization

1. Network Analysis

Research in this field covers the following three areas:

i) state estimation
ii) high speed load flow and stability analysis
iii) non-uniqueness of load flow solution and power system state

In addition to the above three areas, "automatic switching of transmission network (section 4.4)", "stability (sections 3.1 and 3.2)" and "voltage instability (section 3.6)" offer very interesting research subjects closely related to the above three areas. The readers are requested to refer to the sections indicated for research activities in these three areas.

1.1 State estimation

Problems studied in this area are state estimation with deficient data (P_4 +C)*, state estimation technique suited for detecting the overloading of transmission line (P_3), evaluation and improvement

* P, C, M and U stand for power company, CRIEPI, manufacturing company and university respectively.

Table 2. Research Activity

		universities	CRIEPI	power utilities	manufacturers
1. Network Analysis					
1.1 state estimation	↗	3	1	2	
1.2 high speed load flow and stability analysis	↗	4			
1.3 non-uniqueness of load flow and power system state	↗	2			2
total		9	1	2	2
2. Power System Planning					
2.1 methodology of power system planning	→	1	2	2	
2.2 computer aided generator and transmission network planning	↗	1	4	6	
2.3 reliability-availability	↘		1		
2.4 short circuit current	→	2			
2.5 effect of DC technology and UHVAC and DC transmission system	↗	(not appraisable)			
total		4	7	8	
3. Stability					
3.1 basic theory	→	5	1	1	2
3.2 development of practical program	→		1	6	1
3.3 means for stability improvement	→	8	1	5	5
3.4 field tests	↘		1	4	2
3.5 subsynchronous resonance	→		1	4	1
3.6 voltage stability	→	1	2	2	2
total		14	7	22	13
4. Operation and Control					
4.1 basic theory	↘		1	1	
4.2 active and reactive power control of generator and transmission network and line energization	→	3	3	5	
4.3 improved economic dispatching and scheduling	→	2	4	5	
4.4 automatic switching of transmission and distribution network	↗	1		2	2
4.5 security control	↗	2	5	5	1
4.6 computer network for power system operation and control	↗		4	8	3
total		8	17	26	6
5. Protection					
5.1 digital relay	↗		2	2	5
5.2 totally digitalized protection relaying system	↗			1	4
5.3 automatic setting of protective relays	↗			2	1
5.4 improvement of conventional type protection relays	→	(not appraisable)			
total			2	5	10
6. Quality of Electricity Supplied from Power System	→	1	1	6	
7. Social Impact on the Future of Power System	↗	7	3	3	

of state estimation accuracy (U_{13}) and optimization of dynamic state estimation.

So far, the state estimation has been a subject mainly discussed at universities and research institutions. Recently, however, some power utilities are going to apply the state estimation technique for various practical purposes. We expect that this trend will continue for years to come. (Expected growth in the future is represented by upward arrow ↗ in Table 2.)

1.2 High speed load flow and stability analysis

This is an area drawing a strong attention of university prople in Japan. Topics in this area include parallel computation technique (U_6), load flow calculation retaining nonlinearity of power equations (U_2), sparse matrix technique (U_{13}), high speed optimization based on equal increment rule (U_1) Though the power utilities are not so active in this area, CRIEPI is developing a method of simplified load flow calculation aiming at applying it to hierarchical computer network for power system control.

1.3 Non-uniqueness of load solution and power system state

An efficient means has been developed (U_5) which makes it possible to calculate the load flow solution of any of 2^{N-1} modes for the N-node system. This load flow calculation method is being applied to the analysis of voltage instability phenomena. The state of a power system comprising nonlinear elements such as static voltage stabilizer can also not be determined uniquely. This raises many problems which are not only interesting theoretically but also very important from practical viewpoints (U_5) Though the research activity in this area is mainly maintained by universities, some manufacturers (M_1, M_3) are studying similar problems.

2. Power System Planning

This field can be classified into the following 5 areas:

i) methodology of power system planning

ii) computer aided generation and transmission network planning

iii) reliability-availability

iv) short circuit current

v) effects of DC technology and UHV AC/DC transmission system

Research activity in the fields related to power system planning such as stability and security will be discussed later.

2.1 Methodology of power system planning

Topics in this area include the development of procedures for planning optimal reactive power supply installation (C), coordinated expansion and operation planning of high voltage distribution network (C), planning of optimal voltage steps of transmission and distribution networks (P_6) and distribution of optimal operating voltage of 500 kV network (P_6).

As regards generation planning, a university is conducting research on the optimal composistion of nuclear, thermal and hydro plants taking into account the operation of pumped storage plant (U_5) In this area, CRIEPI is most active and contribution of manufacturers is not significant.

2.2 Computer aided generation and transmission network planning

Many power utilities are undertaking extensive R and D work about this problem jointly with CRIEPI (P_1+C, P_2+C, P_6, P_8, P_9+C). Though a university (U_5) is collaborating with a power company, universities and manufacturers are generally inactive in this area. Aiming at establishing a unified system of computer aided power system planning, power utilities are concentrating their effort on the following items:

a) systematic collection, storage and processing of basic data needed for power system planning.

b) development of practical planning-oriented languages for load flow calculation, stability and fault analysis and demand analysis.

c) evaluation of alternative expansion plans

2.3 Reliability-availability

Up to several years ago, research in this ares was active but, at present, main effort on reliability study is directed to stability, security and protection. Particular emphasis is placed upon the **means** to improve the power system reliability and security. The only research subject on reliability-availability under way is "index for evaluating the reliability of power system in steady state" (C).

2.4 Short circuit current

At present, both power utilities and manufacturers are not so nervous about the short circuit current problem. A few universities are doing research on current limiter (U_{10}) and suppression of fault current by transformer impedance matching (U_{13}).

2.5 Effect of DC transmission technology, UHV AC/DC transmission system and unconventional apparatus on the future power system.

To meet the demand for bulk power transmission, power utilities in Japan are concentrating their principal effort on the development of DC transmission technology and UHV AC/DC transmission system. In particular, the UHV AC/DC project is being carried out by power utilities and CRIEPI under the frame of UHV Committee of Central Electric Power Council. Major manufacturers are also doing research on the design and manufacture of UHV apparatus. It is expected that an extensive research on the effect of introduction of UHV AC/DC transmission system on future power systems in Japan will be launched shortly.

As for DC technology, CRIEPI, some power utilities and manufacturers are doing research on all aspects of DC technology. The Ministry of International Trade and Industry (MITI) recently finished the joint research with power utilities, manufactures, research institutions and universities on the role of DC technology in the future power system.

CRIEPI is also doing research on the conceptnal design of cryoresistive and superconducting transmission system.

3. Stability

Power system stability is still one of the major fields drawing the attention of power systems engineers. Research activities in this field can be classified into the following 6 areas:

i) basic theory
ii) development of practical program for stability analysis of multimachine system
iii) means of stability improvement
iv) field tests
v) related topic (1) -subsynchronous phenomena
vi) related topic (2) -voltage unstability

3.1 Basic theory

Theoretical studies are now under way on the following topics: network reduction for short, medium and long term stability analysis (C, P_2, P_5, U_{11}), application of Lyapunov function method (U_{11}, U_{13}), identification of synchronous machine parameters (U_1), stability margin index (U_1), frequency response analysis of power system stability under small disturbance (M_3), dynamic simulation of long term stability (about 10 minutes) taking into account the dynamic response of nuclear plant, protective relays, fault cascading etc. (M_3).

3.2 Development of practical program

This is a problem of common interest to all power utilities in Japan. To develop efficient and practical programs for the analysis of mid-term and long term stability, Stability Committee was organized by Elcetric Cooperative Research Association (ECRA) under the financial support of 10 power utilities and major manufacturers. Many experts from universities, CRIEPI, 10 power utilities and major manufacturers were engaged in this work. Some power utilities are also collaborating individually with CRIEPI and manufacturers for the development of efficient program.

3.3 Means for stability improvement

Universities, power utilities, manufacturers and CRIEPI are intensively studying various means for stability improvement such as post fault insertion of phase shifter (P_4+M_3), static voltage stabilizer (M_6, U_4), fast valving (P_4+M_4), optimal excitation control (M_2, P_4, P_5, P_6), power system stabilizer (U_{12}), DC interconnection (U_{11}), bang-bang control of automatic voltage regulator (U_8), bang-bang control of series/shunt resistor (U_8), forced sequential excitation control (U_8) etc. Power utilities are closely collaborating with manufacturers and CRIEPI in this area. Research activity of universities is limited mainly to laboratory study.

3.4 Field tests

Power utilities are planning and executing field tests to check the effectiveness of the mid-term stability analysis program (P_5+M_4), to study the dynamic response of nuclear plant (P_8+C), to measure the load charac teristics (P_5+M) and to record the dynamic response of power system in fault condition (P_4) Power utilities and manufacturers are closely collaborating with each other in planning and executing field tests.

3.5 Related topic (1)-Subsynchronous resonance (SSR)

Subsynchronous resonance phenomena in case of reclosure failure and of series-compensated system are studied experimentally and theoretically by power utilities and manufacturers (P_3, P_5+M_3, P_8+C).

3.6 Related topic (2)-Voltage Instability

Voltage instability phenomena (P_3+M_3, P_3+M_2, U_5) and countermeasures to prevent them (C, U_5, M_2, M_3) are being studied. This problem also raises theoretically interesting problems such as non-uniquencess of load flow solution and power system state (refer to section 1.3).

4. Operation and Control

State estimation High speed load flow and stabi-This is another field of great interest to power systems engineers in parallel to power system stability. Research activities in this field can be classified into the 6 areas as stated below:

(i) basic theory

(ii) active and reactive power control of generator and transmission network and line energization.

(iii) improved economic dispatching and scheduling.

(iv) automatic switching of transmission and distribution network.

(v) security control.

(vi) computer network for power system operation and control.

It is interesting to note that the research activ ity in this field is mainly maintained by power utilities and CRIEPI.

4.1 Basic theory

Potentiality of state space approach to control efficiency improvement (C) and power system operation based on modern control theory (P_5) is being examined. It should be noted that little participation of university is observable in this area.

4.2 Active and reactive power control, generator synchronization and line energization

Some topics showing the recent research trend in this area are given below.

——wide area reactive power control (P_5)

——local area reactive power control (P_4)

——forced energization of transmission line (P_4)

——forced synchronization of synchronous machine (U_8)

——quick synchronization of hydro turbine-generator (U_8)

——decentralized load frequency control (U_3)

——dynamic control of load flow fluctuation of interconnecting line (P_6+C)

——study on dynamic response of boiling water reactor (C)

——improvement of response characteristics of supercritical thermal plant for load frequency control (P_9+C)

A feature of research activity in this area is that power utilities and universities are individually dealing with diversified subjects according to their need and interest. Little participation of manufacturer is observable except joint work with power utility.

4.3 Improved economic dispatching and scheduling

Economic load dispatching is today a common practice of all power utilities in Japan. However, environmental restrictions on thermal plant operation have recently urged power utilities to develop a new schement of economic load dispatching (P_9, C). Effective operation scheduling of pumped storage plant (U_5, P_5) and large capacity reservoir based on accurate river flow prediction (P_4, P_7) is another important subject for advanced economic dispatching and operation scheduling of thermal and nuclear plants. A university is trying to develop a new scheme of economic load dispatching taking into account power system stability (U_1).

4.4 Automatic switching of transmission and distribution nework

This subject is drawing a very intensive attention of power system engineers in power utilities, manufacturers and universities and we except that the research activity in this area will continue to grow rapidly for years to come though rather limited at present. This problem is being studied not only from theoretical viewpoints (U_1) but also from practical viewpoints (P_3, P_4+M_5, M_1).

4.5 Security control

Extensive studies are being carried out by power utilities and CRIEPI on all aspects of preventive, emergency and restorative controls as well us on the philosophy and basic theory of fault cascading prevention and power system restoration after system wide collapse. Some power utilities (P_2, P_6) are developing elaborate computer algorithms for security control and a power utility (P_4) has many years' records of successful application of system stabilizing controller, of which function they are now trying to strengthen. A manufacturer (M_3) is also developing a computer program to predict the instability mode and to determine the optimal point of system splitting. Universities (U_1, U_8) are also doing research on on-line monitoring of stability and security indices.

4.6 Computer network for power system operation and control

This area has enjoyed a rapid growth in recent years and this trend is expected to grow for years to come.

Problems related to hierarchical computer network for power system operation and control now under study include:

——optimal structure of computer network (C, P_1+C, P_5, P_6)

——evaluation of computer network reliability (P_1, P_2, P_6)

——development of software architecture for automatic dispatching and control (M_1, M_5, P_3, P_1+C, C)

——development of problem oriented language and graphic dislay (P_5+M_1)

No university is participating in the research in this area at present.

5. Protection

To make the best use of transmission capability of network and to maintain the reliability of power system at the highest level, great effort is being concentated on the development of versatile protective relaying system and digital relaying system as well as on the improvement of conventional protective relays. In fact, the gap between advanced computer control scheme and protective relaying system is getting narrower and narrower.

Research in this field is mainly conducted by power utilities and manufacturers. Contribution of university is not significant. Research activities in this field can be classified into the following areas:

(i) development of digital relays using micro-processor and associated measuring instruments

(ii) development of totally digitalized protective relaying system with simultaneous dataa sampling

(iii) automatic computer setting of protective relays

(iv) improvement of conventional protective relays

5.1 Digital relays

Various kinds of digital relays consisting of microprocessors are being developed by manufacturers (M_1, M_2, M_3, M_5) and power utilities (P_3, P_4) Associated digital type measuring instruments are also under development. Problems related to digital relay application (such as noise effect suppression) are being studied by power utilities, manufacturers and CRIEPI. Digital relaying systems for wide area protection are also under study by CRIEPI and manufacturers (M_5).

5.2 Totally digitalized protective realying system with simultaneous data sampling

A power utility (P_3) is now developing under collaboration of manufacturers (M_1, M_2, M_3, M_5) a totally digitalized protectve relaying system with simultaneous data sampling which protects a wide area of power system as a whole.

5.3 Automatic setting of protective relays by computer

Two power utilities (P_3, P_8) are developing digital computer programs for protective relay setting.

5.4 Improvement of conventional type pro-

tective relays

In this area, diversified subjects are being studied as shown below:

——analog type PCM relay (P_3)
——FM differential carrier relay (P_7+M_1, P_4)
——three terminal carrier relay (P_7, P_8, P_9)
——harmonic surge suppression of static relay (P_9)
——fault location of multi-branch ling (P_9+C)
——location of short circuit fault through high impedance ($P_{10}+C$)
——fault location of strongly damped and distorted wave transmission line ($P_{10}+C$)
——automatic self monitoring of relay fault (P_{10})
——Protection of series-compensated line (C)
——response of distance relay in step-out-condition (P_4)

6. Quality of Electricity Supplied from Power System

With the increase of the number and installed capacity of consumers apparatus using semiconducting devices and with the increase of rapidly fluctuating consumer loads (e.g. electric furnace, electric traction car etc.), voltage waveform at consumer ends are greatly distorted sometimes and the power supply voltage fluctuates wildly.

The mechanism of voltage waveform distortion and countermeaures to be taken to prevent waveform distorion and voltage fluctuation as well as their effect on the power system are being studied by power utilities, CRIEPI (P_2+C, $P_4+P_5+P_6+C$, P_4, P_6, P_9) and a university (U_7) Manufacturer's participation is very little.

7. Social Impact on the Future of Power System

Social impact on the future of power system is becoming increasingly serious day by day. Here we mean by "social impact" the social pressure on generating plant siting and route acpuisition of transmission line, environmental restriction, fuel resource limitation and so forth. Technical aspects of power system engineering may seem to play less and less important role in the face of these social impacts. From the long range prospects, however, the ultimate solution to these social problems could not be found except by technical means. Many fields remain untouched before power system engineers, where they can make significant contribution.

Some trial is being made to explore the new horizon of power systems engineering. Some topics in this direction are outlined below:

——role of electric energy in local total energy system (U_1)
——environmental impact on power system (U_6)
——structural stability of power system (U_6)
——load management and electricity pricing ($U_5+P_{10}+C$)
——optimal siting of generating plant and electric consumer (U_7+P_3+C)
——toughness of power system against social impact ($U_5+U_4+P_3+C$)

Universities and CRIEPI are making significant contribution in this field. Though the research activity in this field is of rather limited scale at present, we hopefully expect that it will become increasingly active within a few years.

III. SUMMARY

1. Power utilities and CRIEPI are very active in almost all aspects of power systems research.
2. About 50% of research activity of CRIEPI is made under the joint work with power utilities.
3. Research motivation of manufacturers are mainly stimulated by the need of power utilities and manufacturers are closely collaborating with power utilities.
4. Main effort of universities is concentrated upon the theoretical aspects of network analysis and the means of stability improvement. Univer sities are doing research rather independently of industry unless in exceptional cases. (It should be mentioned that university professors often consult for industry.)
5. Universities are making a significant contribution to the exploration of new horizon of power systems engineering, namely, in the research on the social impact on the future of power system.
6. Current main interest of power systems research is centered around the stability problem and power system operation and control. Research activity in power system planning is rather low as compared to that in these two major fields. A similar statement holds for the analysis of electromagnetic transients and short circuit analysis. However a new research field is sprouting in the area of power system protection.