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AN INTERNATIONAL SURVEY OF THE PRESENT STATUS AND THE PERSPECTIVE OF LONG TERM DYNAMICS IN POWER SYSTEMS

Task Force 02.08
(Long Term Dynamics in Power Systems)
of
Study Committee 38
(Power System Analysis and Techniques)

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Final Report - January 1992

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1. Introduction

1.1 Background of the Questionnaire Survey

Since 1970, there has been considerable interest and effort in both extending the capability of stability simulation and in adding additional components including operator's action to the simulation of stability and several excellent reports have been published as follows :

- EPRI Report PR 90-7, 1974 and EL-367, 1977 "Long Term Power System Dynamics", Volume 1, Phase II
- CIGRE Report 32-13, 1976 "Long -Term Power System Dynamics - A New Planning Dimension"
- CIGRE Report SC-38 WG-02 TF04, 1987 "Advanced Analytical Tools in Evaluating Power System Dynamics and Security Performance"

Dr.N.Flatabø, convenor of TF 38-02-04 at that time, after the publication of the CIGRE report above, distributed a questionnaire on the Long Term Dynamics (L-T-D) probably with the intention of prompting further study in this area.

Based on the response to the questionnaire, the creation of a task force with topic Long Term Dynamics under convenor Prof.Y.Tamura has been decided in WG 38.02 meeting in Arnhem, in March, 1988.

During the CIGRE meeting held in Paris on August 31, 1988, WG 38-02 was reorganized.

In the framework of the new WG 38.02 (Dr. N.Flatabø as convenor), a new TF 38-02/08 on Long Term Dynamics in Power Systems (L-T-D in short) was started with Prof. Y.Tamura as convenor.

On the basis of suggestions and comments on the draft questionnaire from TF 38.02/08 members and WG 38.02 members, the final questionnaire was compiled by Prof. Y.Tamura et al, and was distributed to TF 38.02/08 members and related organizations.

This international survey has received 34 replies on experience of major disturbances, 35 replies for needs and objectives of L-T-D analysis, 30 replies on L-T-D analytical tools and 3 replies for proposed test system from 19 countries as shown in Table 1-1.

The summary of replies to the questionnaire on L-T-D was discussed in TF38.02/08 meeting and presented at WG38.02 meeting (convenor: Dr. Flatabø) in Tromsø, Norway on June 16, 1990. The presented report was the second version of the summary of replies to the questionnaire on L-T-D. On the basis of the discussion in TF38.02/08 meeting, the draft of the final report of the international survey on L-T-D was presented by Prof. Y.Tamura (Convenor) and fully discussed by TF 38.02/08 members at the TF meeting, Florence, May, 1991. Through these detailed discussions, the final report of the international survey on L-T-D was compiled by Prof. Tamura (Convenor).

1.2 Objective of the Questionnaire Survey

The objectives of the questionnaire survey on long term dynamics in power systems are summarized below:

(1) Experience of major disturbances in various countries

- to survey large-scale/medium-scale power system outages in various countries
- to clarify the underlying mechanism of the outages based on after-the fact-analysis
- to identify the connection of the outages with L-T-D

(2) Needs and Objectives of L-T-D Analysis

- to identify the difference of definitions and concepts on long term dynamics
- to clarify needs for the development of long term dynamics analytical tools
- to clarify objectives and functions of long term dynamics analysis

(3) Current status and Perspective of Analytical Tools

- to overview present situation on the development of L-T-D analysis tools, e.g., programs, simulators and hybrid simulators
- to make a comparative study by countries on their concept, function, model, methodology, development environment and performance of L-T-D analysis tools
- to identify the points to be improved and development plans in the future

1.3 General Definitions of the Long Term Dynamics

The phenomena which occur following instability or development of an overload involving a sustained imbalance between load and generation are classified as Long Term Dynamics. The resulting instability or overload in a bulk power system does not directly cause loss of customer load, but rather initiates a sequence of events which may result in the formation of electrical islands, loss of generation by a number of possible mechanisms and ultimately may lead to loss of load by underfrequency load shedding, undervoltage dropout, or the complete collapse of facilities within the island. The period of interest for this type of scenario is from a few minutes up to 1 hour. The transient stability program is not suited to studying this type of disturbance because detailed long-term models are not included and at normal integration time steps of 1-2 cycles the required computation for a long-term simulation is prohibitive.

Three general definitions are shown here so that the scope of the survey can be clearly understood as follows;

- The long term dynamics of a power system are the longer period variations of power flows, voltage, frequency, etc., which occur as the result of sustained mismatches between generation and consumption of active and reactive power. The characteristic times of the voltage and frequency shifts will range from a matter of seconds, corresponding to generator voltage regulator and speed governor action and shaft energy storage, to several minutes, corresponding to load voltage regulator action, to prime mover fuel transfer times and thermal energy storage, and to operator actions. [C.Concordia, D.R.Davidson, D.N.Ewart, L.K.Kirchmayer, R.P.Schulz: "Long-Term Power System Dynamics - A New Planning Dimension", No.32-13,CIGRE 1976]

- The long-term dynamics consist of the slower transient phenomena which become significant in time periods out to tens of minutes. These include the transients of boilers and boiler controls of fossil-fired units, automatic generation control (AGC), operator actions, etc. [R.J.Frowd, J.C.Giri, R.Podmore: "Transient Stability and Long - Term Dynamic Unified", IEEE Trans. on PAS, Vol.PAS-101, No 10 Oct. 1982]

- An electric power system is said to be in a condition of long term stability with respect to a sequence of disturbance that includes or leads to an initial generation/load imbalance, if following the power-frequency transient triggered by the sequence of disturbances it returns to a condition of normal or planned for steady state operation. [N.Flatabø: "Questionnaire on Advanced Analytical Tools in Evaluating

Power System Dynamic and Security Performance" TF 38.02/04, CIGRE 1984]

1.4 Structure of the Questionnaire and Relevant Formats

In order to attain the objectives mentioned above, the questionnaire consists of three parts as follows:

Part A : Experience of Major Disturbances involved with L-T-D in Various Countries

(Question 1)
Major power system disturbances involved with L-T-D in various countries

Part B : Needs and Objectives of L-T-D Analysis

(Question 2)
Objective and function of L-T-D analysis

Part C : Current Status and Perspective of Analytical Tools

(Question 3)
The L-T-D analytical program/simulator development and development schedules

(Question 4)
Application of the developed program/simulator to test systems

(Question 5)
Future development/improvement

For the complete questionnaire please refer to Appendix <1>.

1.5 Reporting

The work of preparing the questionnaire and the report has been shared among members of task force 38.02/08.

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Table 1-1 The Number of Replies for the Questionnaire on L-T-D

Question	Part A: Experience of Major Disturbance involved with L-T-D in Various Countries	Part B: Needs and Objectives of L-T-D Analysis	Part C: Current States and Perspective of Analytcal Tools	
Country	(1) Major Power System Disturbances involved with L-T-D in various countries	(2) Objectives and Functions of L-T-D Analysis	(3) The L-T-D Analytical Program/Simulator Development	(4) Proposed test system
1. Australia	1	1	-	-
2. Brasil	1	1	-	-
3. Belgium	1	1	1	1
4. Canada	2	1	1	1*
5. China	-	-	-	-
6. Czechoslovakia	1	1	1	-
7. Denmark	3	1	-	-
8. Finland	1	1	-	-
9. France	1	1	1	1
10. Ireland	1	1	1	-
11. Italy	1	1	3	-
12. New Zealand	1	1	-	-
13. Norway	1	1	1	-
14. Sweden	1	2	1	-
15. Japan	7	11	11	1
16. U.K.	2	2	2	-
17. U.S.A.	6	6	4	-
18. U.S.S.R	2	2	2	-
19. Yugoslavia	1	1	1	-
Total	34	35	30	4

Note: *, system structure only,
-, not available

2. Experience of Major Disturbances Involved with L-T-D in Various Countries

2.1 Experiences of the L-T-D Outages

In this section replies to the questionnaire regarding the large-scale/medium-scale power system outages involved with long-term dynamics that occurred in the past decade (1981-1990) in the developed countries are presented. The objectives are as given below.

- to survey large scale/medium-scale power system outages in various countries
- to clarify the underlying mechanism of the outages based on after the fact analysis
- to identify the connection of the outages with L-T-D

With the respect to major disturbances involved with L-T-D, as shown in Table 2-1, replies from 34 utilities in 18 countries have been obtained, even though China regrettably failed to provide any reply. In Table 2-1, the locations of the outages, dates of outages, primary causes and scales of outages experienced in the various countries are shown.

Figure 2-1 shows major disturbances involved with L-T-D that have been experienced in different countries. As can be seen in the figure, L-T-D disturbances were experienced in 16 out of the 19 countries, and the rate thereof reaches as high as 84%. On figure 2-1, others represent China which provided no reply.

While Figure 2-1 shows L-T-D disturbances experienced in different countries, it is also considered important to indicate L-T-D disturbances experienced at each utility and in each area, since the United States, Japan and Canada have several utilities and areas (Figure 2-2).

Table 2-1 Experience of Major Disturbance involved with L-T-D in Various Countries

Country	Location of of the outage	Date of the outage	Primary cause	Scale of the outage
1. Australia	1) Queensland Electricity Commission System	April 17, 1990 15:54 Sunday	- Loss of auxiliary supply to smelter substation. A circuit breaker fail relay operated with the subsequent tripping of supply to the smelter	- No other load was shed except hot water supplies which ware normally shed.
2. Brazil	1) Brazilian Southeastern Interconnected System	April 18, 1984 4:43pm Wednesday	- Overload in one of the Jaguara Autotransformers (500/345kv-4x100 MVA)	- Total load rejection in S.PAULO area around 3000 MW - RIO DE JANEIRO and ESPIRITO SANTO areas were almost immediately disconnected. - Blackout in the interconnected part of MATO GROSSO state.
3. Belgium	1) Northern part of Belgium	August 4, 1982	- Loss of a nuclear power plant 764 MW/552 MVA	- Blackout time: from a few minutes to 6 hours
4. Canada	1) Southwestern and Central Ontario	May 31, 1985	- 15 towers on one 500kV double circuit line, two 500kV single circuit double circuit lines blown down by tornadoes.	- Islanding resulting in the loss of 3400 MW of generation, and the interruption of 737 MW of 557 MW of capacity interruptible load (CIL).
	2) Timmis-Abitibi District of the Northeastern Region of Ontario Hydro	November 5, 1985	- Tripping of the 500kV circuit P502X(Porcupine x Hammer) during switching operations at Porcupine.	- Loss of 722MW of generation and interruptions of 190MW of load
5. China	---			

(Continued)

Note; --- not available

Country	Location of of the outage	Date of the outage	Primary cause	Scale of the outage
6. Czechoslovakia	1) South region of Slovakia	July 5, 1985, 9:19 a.m	- Mal-operation of the automatic protective relay	- Consumption area of about 133 MW which belonged to 400kV node in South Slovakia was interrupted. - Total power consumption of 3076 MW was not supplied in IPS, most of which was caused by frequent load shedding. The consumption area in the South Slovakia was connected to the Hungarian deficient Power System after 18 minutes. - The parallel operation of the USSR and Hungarian Power System was restored 37 minutes and the German, Polish and Czechoslovakia Power System were put into parallel operation 9 minutes later.
7. Denmark	1) ELKRAFT	March 2, 1979	- Loss of a single generator	- Area affected ; 300 MW - Interrupted supply ; 50 MW - Total time until system was normal ; 30 min.
	2) ELKRAFT	August 1, 1989	- Loss of a single generator	- Area affected ; 1600MW - Interrupted supply ; 0 MW - Total time until system was normal ; 20 min.
	3) Tie line between Sweden and ELKRAFT	December 27, 1983	- Equipment failure in Sweden station	- Total load at ELKRAFT; 1600MW - Interrupted supply ; 540MW - Total time until system was normal ; 1 h. 30 min.
8. Finland	No			

(Continued)

Note; --- not available

Country	Location of of the outage	Date of the outage	Primary cause	Scale of the outage
9. France	1) The North-West quarter of France	December 1, 1987 11:40 a.m.	- Three units tripped in Cordemais between 11.30 a.m. and 11.40 a.m. for different independent reasons. - The disturbance caused by the loss of the third unit caused the final Cordemais unit to trip, following incorrect operation of the voltage regulator.	- 8000MW of supply was loss at the peak of the incident. - Over the whole of the incident, this corresponds to a non-distributed energy of 14000MW - The zone affected included Brittany and certain areas which were cut selectively (priority supples were unaffected) - Supplies were restored to most customers by 3 PM, and the situation was returned to normal by 8 PM.
10. Ireland	1) Electricity Supply Board Ireland	June 28-29, 1986 19:00-00:00	- Widespread single and multi-phase short circuits due to countrywide thunderstorm	- Southern system generation surplus led to frequency rise to 51.8 Hz and caused 270MW generators to trip, frequency quickly restored to 50Hz. - On Northern system generation deficit leads to tripping on underfrequency of pumping units at pumped storage plant Turlough Hill and frequency fall to lowest of 47.65Hz leading to shedding an underfrequncy relay operation of 40% customer load in isolated northern section. - Within two minutes frequency is restored to 50Hz by pump storage plant voltage control lost on northern network until system resynchronised at 0.55 hrs.
11. Italy	1) Separation of ENEL System from European one	May 10, 1989 About 5:00 p.m.	- Opening of the 380kV double circuit Rondissone-Albertville(between Italy and France), caused by distance protections due to storm	- The automatic load-shedding was about 4900MW - Starting form separation instant the parallel with the European system has been restored in 10 min. - All shedded loads(automatically and manually) were re-supplied in other 10 min., for a total duration of impact of the incident of about 20 min.

(Continued)

Note; --- not available

Country	Location of of the outage	Date of the outage	Primary cause	Scale of the outage
12. New Zealand	1) Top half on North Island of New Zealand	February 6, 1987 20:48	- Explosion in head of a generator circuit breaker at Whakamaru Power Station (Code=WKM)	- Loss of supply to northernhalf of North Island. - Lost Load : 730MW - Lost energy ; 808MWh(estimate)
13. Norway	No			
14. Sweden	1) Southern Sweden	December 27, 1983	- Short circuit in faulted isolator, causing total disconnection of the 400kV switchgear. (Under normal conditions only half the switch gear would have been disconnected)	- Some 11,000MW was lost. - The outage lasted from 30 minutes to 8 hours. However, most of the loads were reconnected after 4 hours.
15. Japan	1) Someplace in Chubu area	Aug. 14, 1987, 14:34	- Thunder storm	- Interrupted power supply 646 MW - Outage duration time about 10 minutes
	2) EG power system in Hokuriku	July 17, 1989, 4:37	- KA transmission line was tripped by thunderbolt, so EG system was separated from bulk power system.	- Interrupted power supply 187MW/41MWh - The outage time ; 1 - 21 minutes
	3) Local city in Shikoku area	June 13, 1988, 7:52	- Internal fault of bus tie CB (CB1)	- Amount of outage; approximately 60 MW - Time outage ; 36 min. (the longest)
16. U.K.	1) South East England	October 16, 1987 Early hours of Friday	- The incident began with the loss of 400kV transmission circuit along the South east of England due to severe weather condition.	- The power supply to London and South East England was interrupted with loss of about 2600Mw demand. - The power supply to Supergrid point was restored within a few hours.

(Continued)

Note; --- not available

Country	Location of of the outage	Date of the outage	Primary cause	Scale of the outage
17. U.S.A.	1) Southweston Wisconsin	March 5, 1984	- Failure of a splice in a phase conductor caused the Darling-North Monroe-Rock River 138kV line to trip	- The net result was the loss of about 150 MW of load cover a 6-county area
	2) Gainesville, Florida	July 28, 1984	- At 1322 EDT, protective devices detected a fault in the 100MVA transformer T-76 at the Parker Substation and opened both the high-side and low-side breakers.	- All three generating units on line tripping due to protective devices.
	3) Lakeland, Florida	August 6, 1984	- Lakeland's McIntosh Unit 3 (364MW) tripped due to a boiler swing following loss of a coal mill.	- Lakeland lacked 69kv voltage support with the result that system voltage dropped to 60 kV(87%)
	4) WSCC Wyoming	July 8, 1985	- A switching error that resulted in 230kV air switch 1H431 at Midwest failing to interrupt line charging current on the Midwest-Casper 230kV line	- Voltages on the 115 kV and 69 kV systems dropped and approximately 10 MW of oil pumping load was lost due to low voltage.
	5) NPCC New York	October 31, 1985	- A phase-to-phase fault at the Edi 345 kV transmission station located in central upstate New York	- The loss of 1630MW in New York, 1800 MW total loss to the Eastem interconnection, resulted in a steady-state frequency drop of about 0.036 Hz
18. U.S.S.R.	1) The south part of the west Siberia	September 8, 1988 11:28	- Disconnection of TL 220kV between E and ES1 were by relay	- The value of the interrupting power were equal to 160 MW, interrupting energy were 85 kWh.
	2) South Siberia	September 27, 1986 10:11	- TL 300kV between ES1 and ES5 were disconnected by relay protection.	- Disconnected power ES1 was 660 Mw, ES2-510MW. - Energy interrupt ES1-270 t.kWh. ES2-398 t.kWh. Discontinuance time of energy to ES1-29 min. to ES2-61 min.
19. Yugoslavia	1) West part of the Yugoslavia Power System	August 1, 1986	- Protection device fault	- The loss of 300+300MW generator unit, blackout in 4 hours

Note; --- not available

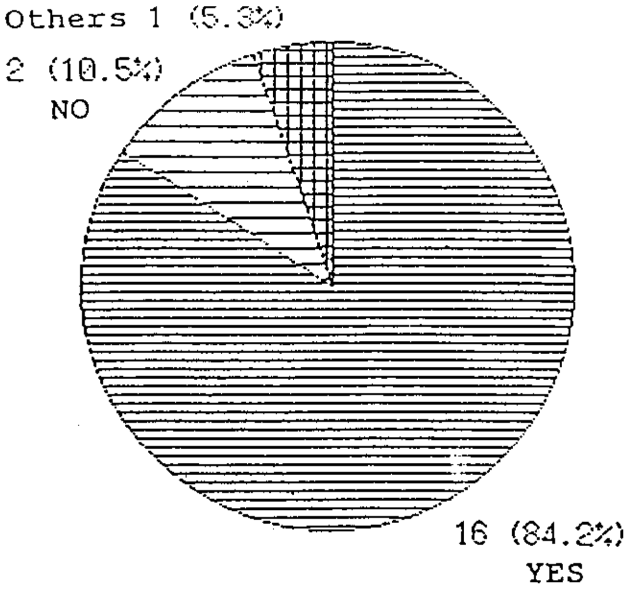

Figure 2-1 Experience in major disturbances by country

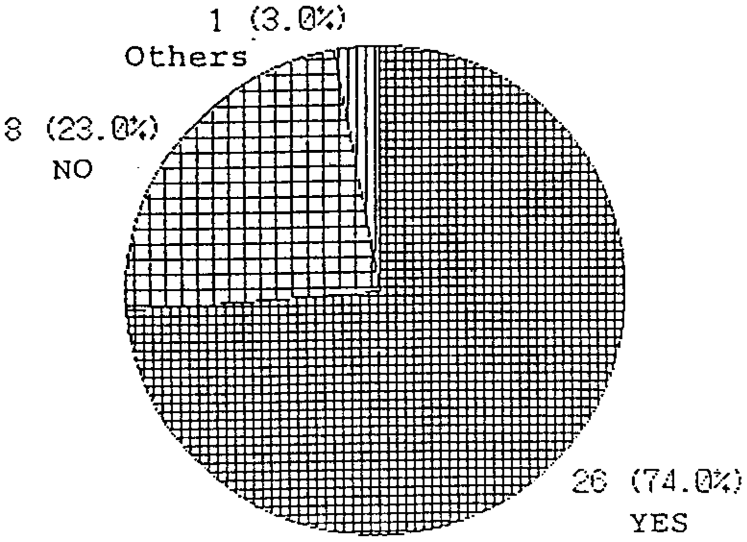

Figure 2-2 Outage experiences by utility and area

2.2 The L-T-D Outages in Each Country

Table 2-1 indicates L-T-D disturbances experienced at each utility and each area. As is evident from the figure, it was the United States that provided most the numerous replies regarding major disturbances involved with L-T-D, since the country mentioned 5 cases of L-T-D involved outages. These represents outages concerning L-T-D gleaned from the NERC reports. The United States is followed by Denmark and Japan with 3 outages each, which in turn are followed by Canada and U.S.S.R with 2 outages cases each. Australia and others reported 1 case of outages each. A large-scale voltage collapse that occurred in the southwestern area of Tokyo in the summer of 1987 is reported, but the absence of details is regrettable. The number of L-T-D cases rapidly increases from around 1982 to 1985. Outages during this period have occurred mostly in the advanced countries centered around the United States and Europe. Outages reached the peak between 1985 and 1987, but the number of cases gradually decrease thereafter. During the period however the occurrences of large-scale L-T-D in Canada and France as well as in Japan have been reported. The latest L-T-D has been observed in Australia; it gave rise to a power failure lasting more than an hour.

2.3 Outline of the Outages

The initial causes of L-T-D development are classification in Figure 2-3. Leading causes are indicated as mal-operation of protective devices, severe weather and equipment fault. Meanwhile, causes of outages leading to large-scale disturbances are given in Figure 2-4. Among the causes, the most numerous was over-load on equipment, which accounted for about 30% of the total. This was followed by frequency deviation (23%) and voltage decline (23%). It is thus evident that the effects of outage spread over wider areas together with phenomena peculiar to L-T-D, such as over-load, frequency deviation and voltage decline.

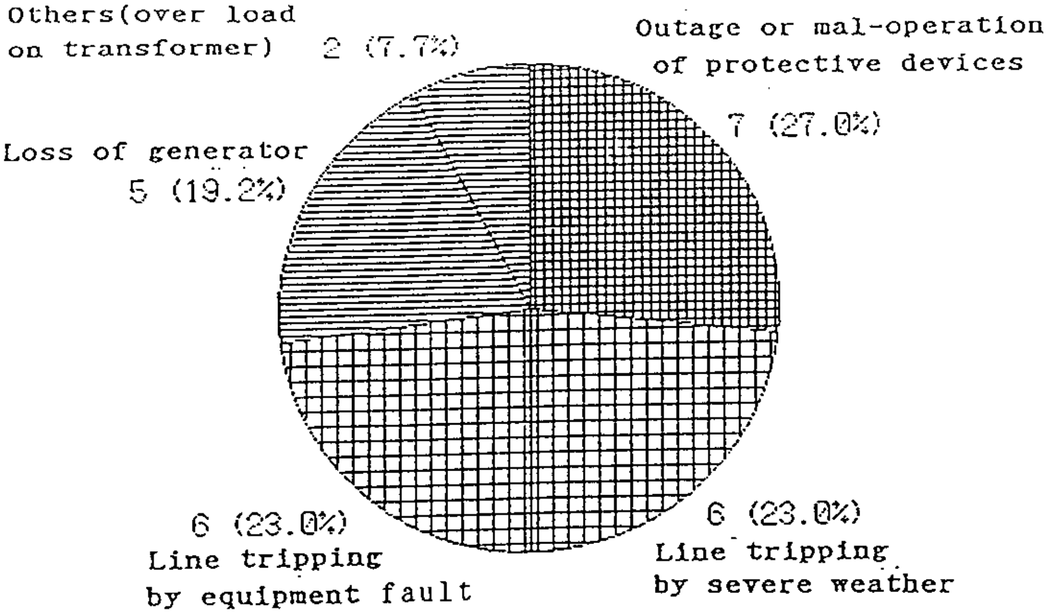

Figure 2-3 Initial causes of L-T-D occurrence

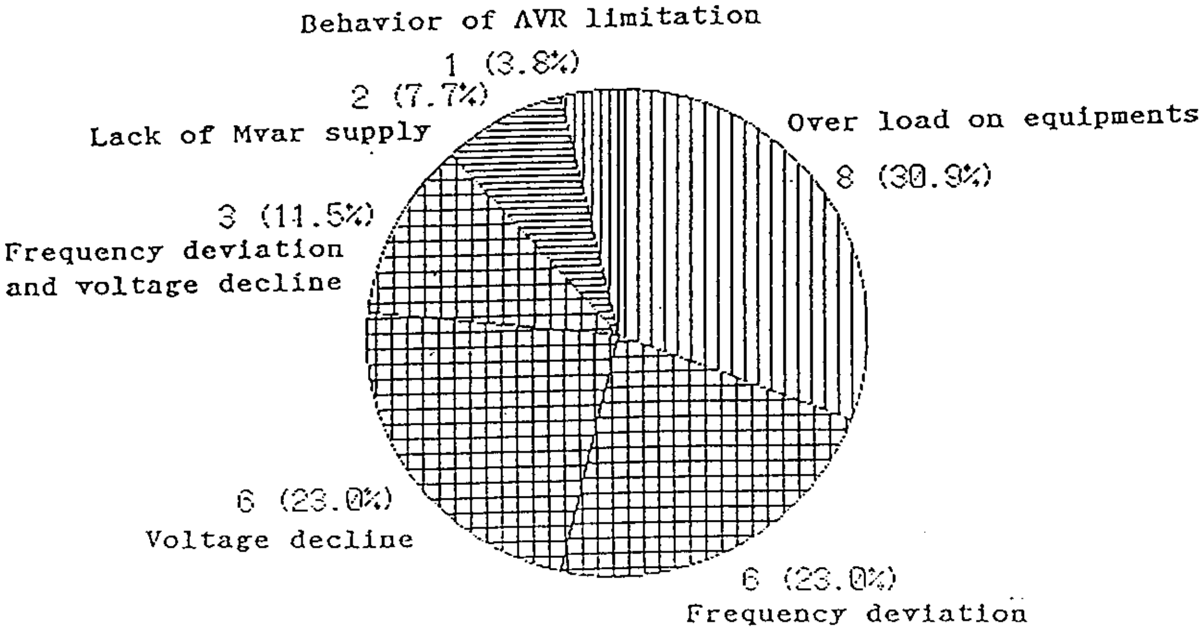

Figure 2-4 Causes of outage spread


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3. Needs and Objectives of L-T-D Analysis

3.1 Definition of Long Term Dynamics

In this chapter studies relevant to the subjects cited below have been undertaken for the purpose of bringing into relief the features and differences in the needs and objectives of L-T-D analysis, the state of development of the major functions found in the various countries.

- to identify the difference of definitions and concepts on long term dynamics
- to clarify needs for the development of long term dynamics analytical tools
- to clarify objectives and functions of long term dynamics analysis

With regard to the definition of long-term dynamics, replies have been received from 16 countries, and full transcriptions of the definition have been compiled in Table 3-1. While the definition of long-term phenomena of several seconds to several tens of minutes based on the physical causes and phenomena is the common feature.

The typical new definitions of L-T-D in the replies are as follows;

(1) Belgium/France

In the past, electromechanical transients (related to the unit rotor oscillations and the possible loss of synchronism) and long-term dynamics (disregarding the individual rotor oscillations and making the assumption of a common angular velocity of the rotors) were analyzed separately.

But the actual physical phenomena are mixed : For instance, rotor oscillations can occur spontaneously as a result of a slow increase of a power transfer, and short-term phenomenon, like a

Table 3-1 The Definition of Long Term Dynamics (L-T-D)

Country	Definition of Long Term Dynamics (L-T-D)
1. Australia	-
2. Brazil	Extended dynamic performance of electrical power systems which occurs as the result of sustain mismatch between generation and load - Active and/or reactive power.
3. Belgium	In the past, electromechanical transients (related to the unit rotor oscillations and the possible loss of synchronism) and long-term dynamics (disregarding the individual rotor oscillations and making the assumption of a common angular velocity of the rotors) were analyzed separately. But the actual physical phenomena are mixed : For instance, rotor oscillations can occur spontaneously as a result of a slow increase of a power transfer, and short-term phenomenon, like a line tripping, can provoke long-term disturbances (through rotor protection, or overload protection action, etc...). Therefore, for an accurate study of the dynamic behaviour of the power system, we need an extended modeling of all kinds of phenomena, in the same simulation calculation: - electromechanical transients with the associated short time constants of the rotor and of the excitation system; - turbines and boilers behaviour with their slower dynamics; - protection devices, automatons and centralized controllers actions. In our option, L.T.D. are related to the behaviour of the systems taking into account all these phenomena during the period of time ranging from a ten of seconds up to a few hours. [TRACTEBEL]
4. Canada	The long-term dynamics of a power system are the relation in power flows, voltages, frequency etc., occurring in the time frame extending from a few seconds to tens of minutes. These variations can be caused or influenced by a wide variety of protective and control actions ranging from the relatively fast actions of devices such as voltage regulators and governors (time frame of seconds) to the relatively slow control actions of devices such as boiler controls, AGC as well as operator actions (time frame of minutes) [Ontario Hydro]
5. China	-
6. Czechoslovakia	The long Term Dynamics are not generally defined in Czechoslovakia. In the Power Research Institute we understand the Long Term Dynamics as long term unbalance between the generation and consumption which is accompanied with the voltage and frequency fluctuations. The phenomena mainly belongs to the secondary control of active and reactive powers. If the Long Term Dynamics are not properly solved they may lead to the voltage collapse, instability, overload and to formation of electrical islands. [Power Research Institute Brno]

Note: - , not available

(Continued)

Country	Definition of Long Term Dynamics (L-T-D)
7. Denmark	Dynamics involving tap changing in the network, boiler dynamics at the power stations or changing of voltage or power references in the system, either automatic or manual. [ELKRAFT]
8. Finland	L-T-D are the longer period variations of power flows, voltage, frequency, etc. which occur as the result of sustained mismatches between generation and consumption of active and reactive power. The characteristic times of the voltage and frequency shifts will range from a matter of seconds, corresponding to generator voltage regulator and speed governor action and shaft energy storage, to several minutes, corresponding to load voltage regulator action, to prime mover fuel transfer times and thermal energy storage and by operator action of fast reserves activated in 15 minutes. [Imatran voima Oy]
9. France	In the past, electromechanical transients (related to the unit rotor oscillations and the possible loss of synchronism) and long-term dynamics (disregarding the individual rotor oscillations and making the assumption of a common angular velocity of the rotors) were analyzed separately. But the actual physical phenomena are mixed : For instance, rotor oscillations can occur spontaneously as a result of a slow increase of a power transfer, and short-term phenomenon, like a line tripping, can provoke long-term disturbances (through rotor protection, or overload protection action, etc...). Therefore, for an accurate study of the dynamic behaviour of the power system, we need an extended modeling of all kinds of phenomena, in the same simulation calculation: - electromechanical transients with the associated short time constants of the rotor and of the excitation system; - turbines and boilers behaviour with their slower dynamics; - protection devices, automatons and centralized controllers actions. In our option, L.T.D. are related to the behaviour of the systems taking into account all these phenomena during the period of time ranging from a ten of seconds up to a few hours. [EDF]
10. Ireland	ESB is concerned with the effects of losing two or more of the large sets in our base load coal-fired station particularly at a light load period. The likely consequences are widespread underfrequency load-shedding, large Mvar imbalances, with rising voltage leading to transformer saturation and tripping of transformers due to overfluxing. [Electricity Supply Boad]
11. Italy	The long-term dynamic behaviour of an electric power systems is mainly determined by the response, following perturbations, of the slow controls acting on the network or to the phenomena related to : primary frequency control; behaviour of the supply systems and of the prime movers; load-frequency control(or secondary frequency control); secondary voltage control; operation of the over and under excitation limits of the units; action of on-load tap-changers; action of overload relays, under and over frequency relays, under voltage relays. It is worthwhile to note that a particular aspect of long-term dynamics is that of the so-called "voltage instability" mainly due to slow voltage controls (on-load tap-changers, secondary regulation), and sometimes with their interaction with slow frequency regulations, as well as the possibility that the generators may operate at the over-excitation limit. [ENEL]

(Continued)

Note: - , not available

Country	Definition of Long Term Dynamics (L-T-D)
12. New Zealand	Conventional definitions [Trans Power New Zealand Limited]
13. Norway	-
14. Sweden	The dynamics of a power system include slow and rapid phenomena which are mixed together. Sudden transient stability phenomena may occur during slow frequency control actions and manual changes. A limited definition of L-T-D assumes that no unstable rapid phenomena happens. Thus the L-T-D may be defined as "voltage and frequency dynamics that assume a quasi-stationary angle differences between generators", i.e. the no attention is rapid to internal angle oscillations between generators. THe L-T-D take the following phenomena into account; - power flow - frequency control (primary and secondary) - voltage control (stationary gain of primary control, and secondary control actions) - relay protection (due to overload) control actions (load shedding due to low frequency) manual actions [Vattenfall and RIT]
15. Japan	(1) We think L-T-D as the phenomena of duration from 1 - 2 minutes to 1 hour. [Meidensha Co.]
	(2) The long term dynamics of a power system are the variations of power flows, voltage, frequency, etc. caused by imbalance of active and reactive power from tens of seconds to tens of minutes. [Hokuriku E.P.Co. and Toshiba Co.]
	(3) The slower transient phenomena about which we should take into account not only the speed governor action, the AVR action but the plant action, the load change. [Shikoku E.P.Co.]
	(4) L-T-D consist of two parts. One is rather shorter period variation of the electrical phenomena including the urgent movement of the plants like load-anticipator. The other is rather longer one that including the movement of boilers. [Chubu E.P.Co.]
	(5) We basically agree with the definition by Dr. C. Concordia, et al in the paper No.32-B, CIGRE 1976. However, it should be recognized that automatic generation control (AGC) would affect to the L-T-D under some circumstances. Regarding to human factor or human engineering, L-T-D itself include it, however, in the analytical tools of L-T-D it would not be necessary to include it except input data setting or simple logic or operator action. [CRIEPI]
	(6) Power system dynamic behavior which sustains 5 - 20 minutes. [Mitusbishi Electric Co.]
	(7) Dynamic of power system with the long period variations of power flow, voltage, frequency, etc. (from several seconds to tens of minutes) which occur as the result of sustained mismatches between generation and consumption of active and reactive power. [Electric Power Development Co.]
	(8) The long term dynamics of a power system are the longer period variation of power flow, voltage, frequency, etc., which occur as the result of sustained mismatches between generation and consumption of active and reactive power and the sequence of disturbances. [Fuji Electric Co.]
	(9) No concrete definition on L-T-D, but we are in accordance with the definition from CIGRE paper 32-13 (1976) (Concordia, Davidson, Ewart, Kirchmayer, Schulz) including AVR and govonor in the time range of several seconds, thermal plants behavior and operater's intervention in the time range of several minutes. [Kyushu E. P. Co.]
	(10) No specific definition on L-T-D, but the voltage instability problem under study can be categolized into the L-T-D phenomenon. [Kansai P. E. Co.]

Note: - , not available

(Continued)

Country	Definition of Long Term Dynamics (L-T-D)
16. U.K.	(1) No definition of LTD exists within Scottishpower. [ScottishPower]
	(2) The long term dynamics of a power system are the long-term phenomena (up to about 10 mins) involving the variation of power flow, voltage and frequency, etc, which occur as the result of sustained mismatches between generation and load generally arising from loss of generation, load or circuits, circuit overloading and cascade tripping of circuits. [National Grid Co. plc]
17. U.S.A.	(1) The definition form CIGRE paper 32-13 (1976) (Concordia, Davidson, Ewart, Kirchmayer, Schulz) is still valid now, 14 years later. Long term dynamics begin at the instant of the first disturbance. [American Electric Service Corp.]
	(2) Beyond 1 second. [ECC, Inc.]
	(3) Dynamic behaviour of power system caused by generation - load imbalance; behavior of system frequency, prime-mover and relay actions. [ESCA Corp.]
	(4) Long term Dynamics of a power system are the effects of large voltage, frequency and power flow excursions occurring with slower acting phenomena over periods lasting several minutes to several hours after initiated by a major disturbance. [Wisconsin Electric power Co.]
	(5) Any incident extending past about 10 seconds beyond initiation which includes such component events as LTC's, load diversity, prime mover control, excitation limiter, element overload AGC, boiler dynamics, DC converters, and operator intervention. [EPRI]
18. U.S.S.R.	(1) The long term dynamics in power systems are electromechanical thermophysical and hydrolic transients in an electric system and generating equipment of electric power systems, which have duration from 1-2 min to 10-15 min and occur as result of sudden significant imbalance of active power or/and changes in electric network. They are companying by large variations of power flows, voltage, frequency and lead to anti-fault automatic systems actions, instability and/or system separation on electrical islands. [Electric dynamic Inst.]
	(2) We are in accordance with all definitions are given in the questionnaire survey. [Power Institute in Sibiria]
19. Yugoslavia	(1) No exact definition, but using conventional definition as: variation power flow, voltage and frequency, angle oscillation resulted in instability during 0.01 sec. up to a few minutes [Power System Institute]

Note: - , not available

line tripping, can provoke long-term disturbances (through rotor protection, or overload protection action, etc...).

Therefore, for an accurate study of the dynamic behaviour of the power system, we need an extended modeling of all kinds of phenomena, in the same simulation calculation:

- electromechanical transients with the associated short time constants of the rotor and of the excitation system;
- turbines and boilers behaviour with their slower dynamics;
- protection devices, automatons and centralized controllers actions.

In our option, L.T.D. are related to the behaviour of the systems taking into account all these phenomena during the period of time ranging from a ten of seconds up to a few hours. [TRACTEBEL and EDF]

(2) Sweden

The dynamics of a power system include slow and rapid phenomena which are mixed together. Sudden transient stability phenomena may occur during slow frequency control actions and manual changes.

A limited definition of L-T-D assumes that no unstable rapid phenomena happens. Thus the L-T-D may be defined as "voltage and frequency dynamics that assume a quasi-stationary angle differences between generators", i.e. the no attention is rapid to internal angle oscillations between generators. THe L-T-D take the following phenomena into account;

- power flow
- frequency control (primary and secondary)
- voltage control (stationary gain of primary control, and secondary control actions)
- relay protection (due to overload)

  control actions (load shedding due to low frequency)

  manual actions

[Vattenfall and RIT]

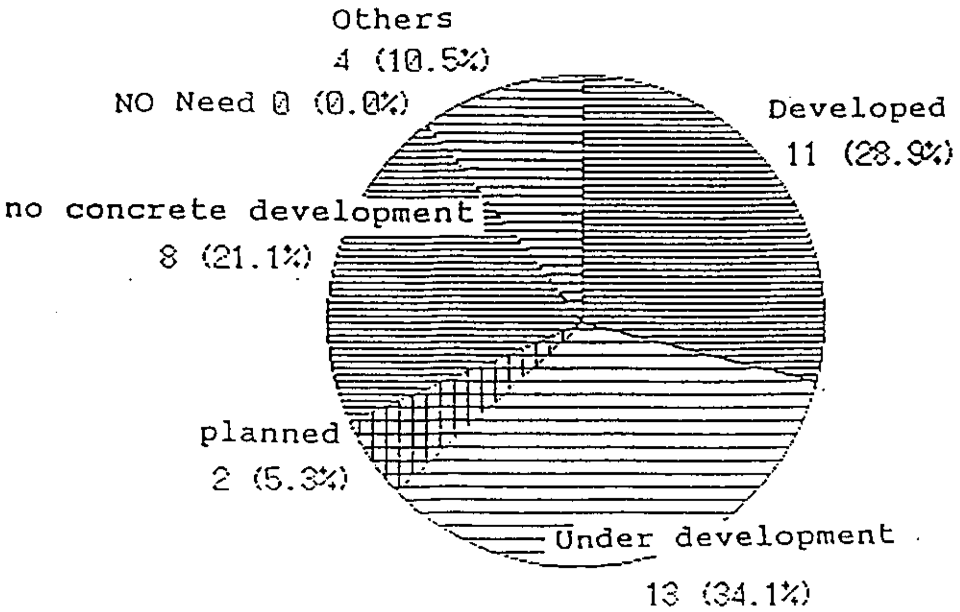

Figure 3-1 Stage of the L-T-D analysis tools development in various countries

3.2 Development Stage of L-T-D Analysis Tools

Figure 3-1 represents a compilation of the L-T-D analytical program/simulator development levels in the various countries. Simulators already developed and those under development account for 65% of all the responses, and when the development under planning is included, these account for more than 70%. From the above result, the fact that the countries concerned are deeply interested in L-T-D and that they have a positive attitude towards development can well be understood.

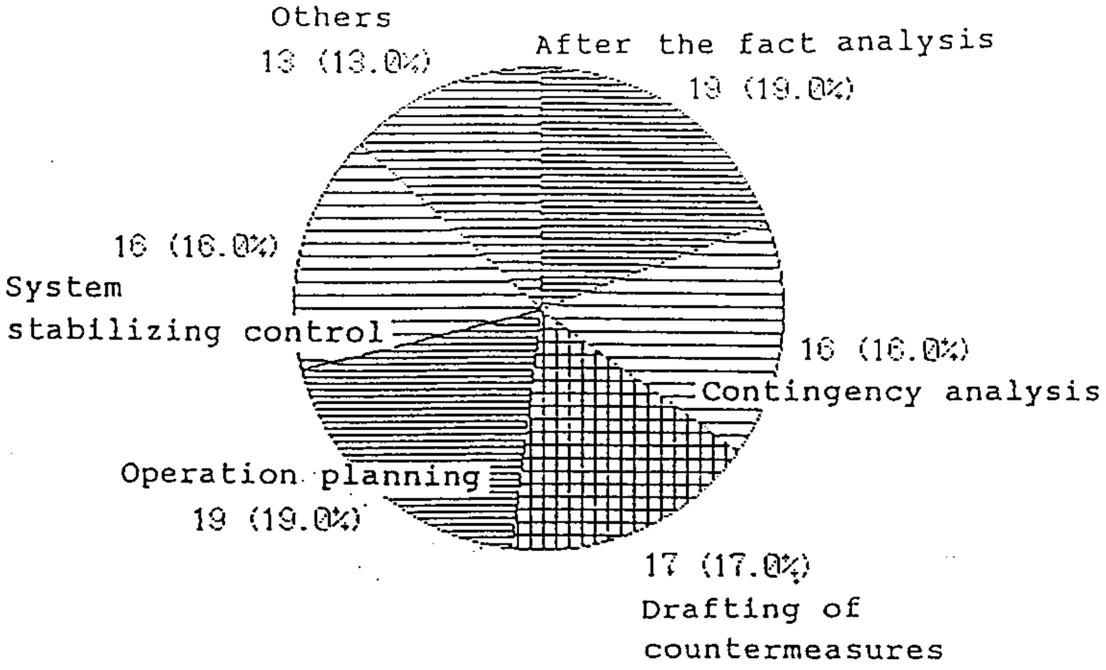

Figure 3-2 Objectives of the L-T-D analysis tools development

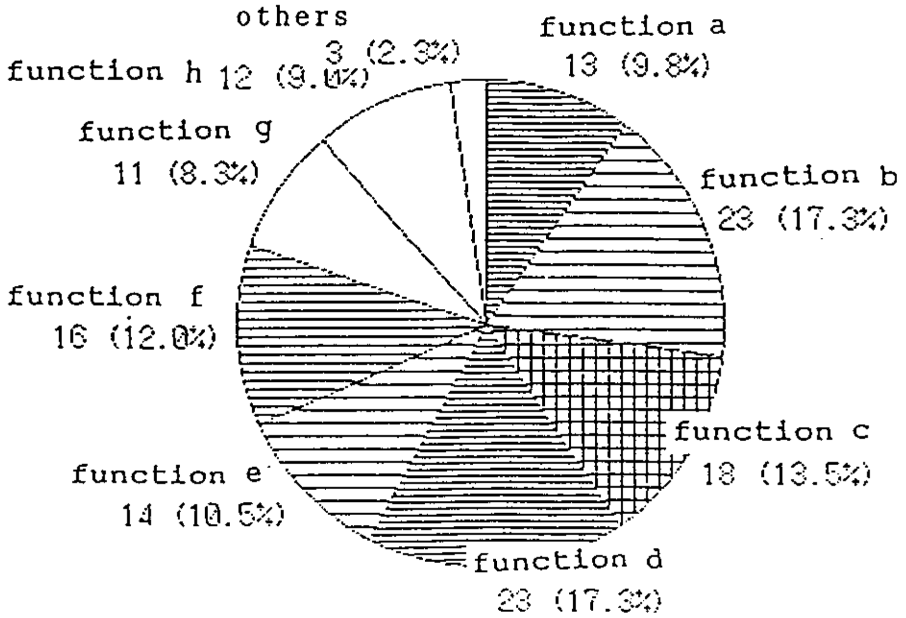

Figure 3-3 Major functions of L-T-D analysis

3.3 Objectives and Functions of L-T-D Analysis

Figure 3-2 shows the objectives of the L-T-D analytical program and simulators already developed or under development. Several responses have been provided by the various countries and on the average 4 objectives of development are cited in the response of each country. The ratio of responses given to the objectives, such as after-the-fact analysis, contingency analysis, drafting of countermeasures, operation planning and system stabilization control is approximately equal, with the value ranging around 20%. Accordingly, the fact that the development objectives of the various countries are plural in number and that the development policies of the various countries are generally in agreement can be assumed.

Figure 3-3 represents a compilation of the responses related to the major functions of L-T-D analysis, and the individual functions of L-T-D as given below.

function a: to clarify the construction of the system which brought the outage spreading

function b: to analyze the underlying mechanism of the outage spreading and to avoid a cascade of outage after the initiating event

function c: to clarify the behavior of various plants (thermal, nuclear, hydro, etc.)

function d: to study the control system such as overload releasing, generator tripping, load reduction by lowering voltages, system separation, load shedding, etc.

function e: to determine and coordinate the set point of frequency/overload relays

function f: to investigate the AGC operation performance for system stabilization

function g: to determine the necessary amount and the location of spinning reserve

function h: to develop the training simulator for L-T-D analysis

Several replies related to the above functions were provided by the various countries. The replies to function A through H were approximately equal in ratio. In other words, the replies have indicated that the various countries were faced with several major functions and that their development policies were about the same.

4. Current Status and Perspective of Analysis Tools

The study of the existing state of the L-T-D analysis tools of various countries was undertaken for the following purpose:

- to overview present situation on the development of L-T-D analysis tools, e.g., programs, simulators and hybrid simulators
- to make a comparative study by countries on their concept, function, model, methodology, development environment and performance of L-T-D analysis tools
- to identify the points to be improved and development plans in the feature

Detailed items of the study are given in Table 4-1 together with the project name, the developing organization and the development stage at the time of study (March 1990). The countries studied totaled 19, but, as shown in Figure 4-1, the countries that were engaged in the developed of L-T-D analysis tools, including the planning stage, at the time of study numbered 12.

Among the 12 countries undertaking development of L-T-D analysis tools, some had two or more development projects going on. Figure 4-2 gives the aggregate number of projects being undertaken in the countries engaged in the development of L-T-D analysis tools. Japan's projects totaled nine, the largest number among the countries, and this was followed by the United States' four.

Figure 4-3, meanwhile, gives the L-T-D analysis tool development stages in the various countries at the time of study. The operating tools were predominant, and these, together with tools under testing, accounted for 60% of the total.

Table 4-1 The L-T-D Analytical Program/Simulator

country	Name of the project	Name of the organization	Stage of the development (as of May '90)
1. Australia	-		
2. Brazil	-		
3. Belgium	1) EUROSTAG	TRACTEBEL / ELECTRICITE DE FRANCE	Operational
4. Canada	1) ETMSP	Ontario Hydro	Planning, Prototyping
5. China	-		
6. Czechoslovakia	1) Intelligent System for L-T-D Analysis	Power Research Institute, Brno	Testing Operational
7. Denmark	-		
8. Finland	-		
9. France	1) EUROSTAG	ELECTRICITE DE FRANCE / TRACTEBEL	Operational
10. Ireland	1) Remote Plant Monitoring	Electricity Supply Board	-
	2) PSS/E Extended Term Dynamic Section	Power Technologies Inc.	Testing
11. Italy	1) Digital Program: STRALE	ENEL	Operational
	2) Real time Prototyping of Power System Simulator:PPSS	ENEL	Operational
	3) Final Simulator; SICRE	ENEL	Under development
12. New Zealand	-		
13. Norway	-		
14. Sweden	1) Fast Power System Simulator; FPSS	Vattenfall, EKC at RIT	Prototyping

Note : -, No reply or unknown

(Continued)

country	Name of the project	Name of the organization	Stage of the development (as of May '90)
15. Japan	1) Undecided	Meidensha Corporation	Planning
	2) Advanced Power System Simulator(APOSS)	Hokuriku Electric Power Co./ Toshiba Corporation	Operational
	3) The Development of long Term Dynamic analytical program	Chubu Electric Power Co./ Mitsubishi Electric Co..	Planning
	4) Advanced Power System Analyzer (APSA)	Technical Research Center Kansai Electric Power Corporation Ltd. / Fuji Electric Co., Ltd.	Operational
	5) Development of the Long Term Dynamics Digital Simulator	Electric Power Development Company	Testing
	6) Analysis of Voltage Decline	Tokyo Electric Power Co./ Mitsubishi Electric Co.	Prototyping
	7) Simulator for Power System Analysis	Kyushyuu Electric Power Co.	Planning
	8) Simulation software for Power System Voltage Collapse	Central Research Institute Electric Power Industry; CRIEPI	Operational
	9) Y method Power System Dynamics Simulation Program	CRIEPI	Operational
	10) AGC Simulation Program	CRIEPI	Testing
	11) Transient Network Simulator(TNS)	Fuji Electric Co., Ltd.	Operational
16. U.K.	1) Long Term System Dynamic Simulation Program (EUROSTAG)	TRACTEBEL	Testing
17. U.S.A.	1) Training Simulator	ESCA Corp.	Operational
	2) AGCSIM2	ECC, Inc.	Operational
	3) Extended Term Program Section of PSS/E	Power Technologies Inc.	Testing
	4) Long Term Power System Dynamics	Electric Power Research Institute (EPRI)	-
18. U.S.S.R.	1) ABP-14 program	Electric dynamic Inst., Kiev	-
	2) -	The Research Institute of Power in Siberia(Novosibirsk)	-
19. Yugoslavia	1) Dynamic Model of the Power System Behaviors	Power system Inc. ELECTROPRIVREDA SARAJEVO	Operational

Note : -, No reply or unknown

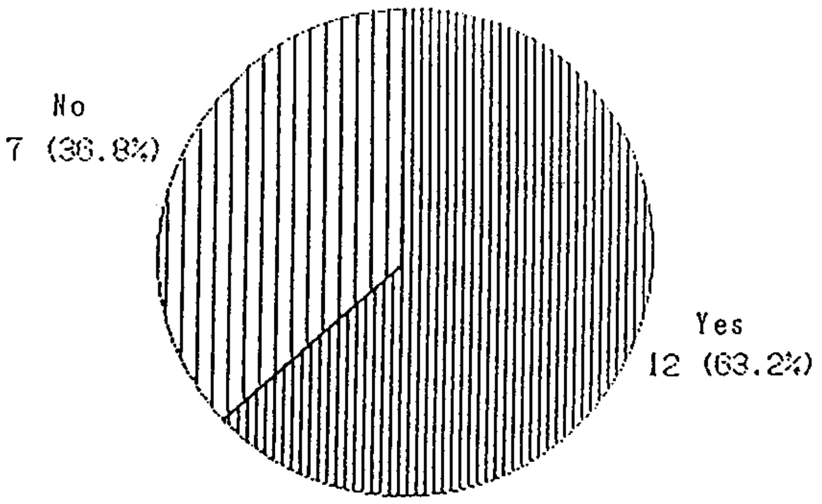

Figure 4-1 Development of the L-T-D analysis tools in the various countries

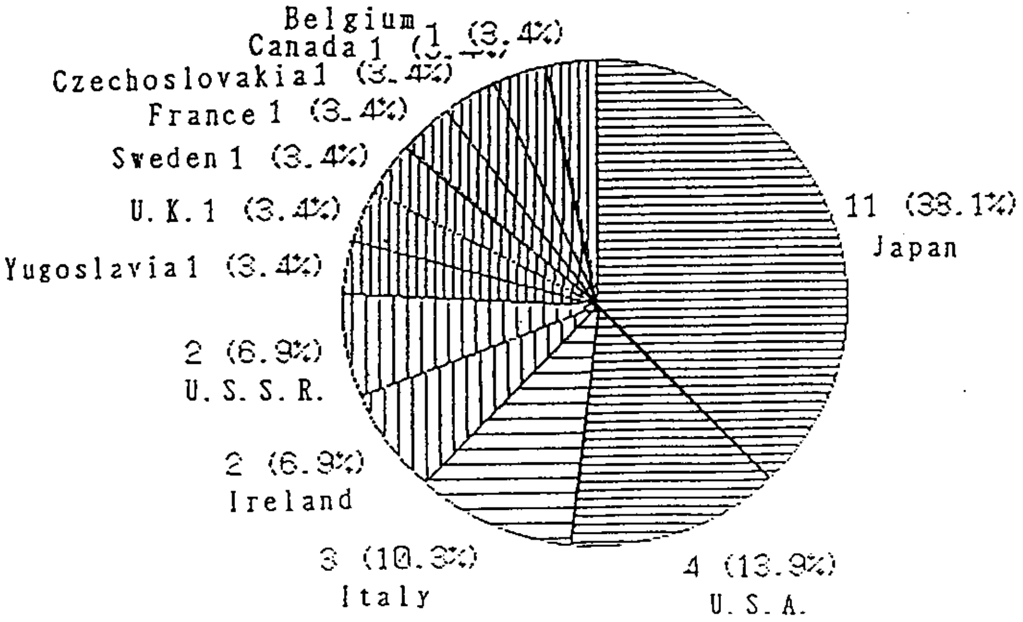

Figure 4-2 The number of L-T-D tool development projects in the various countries

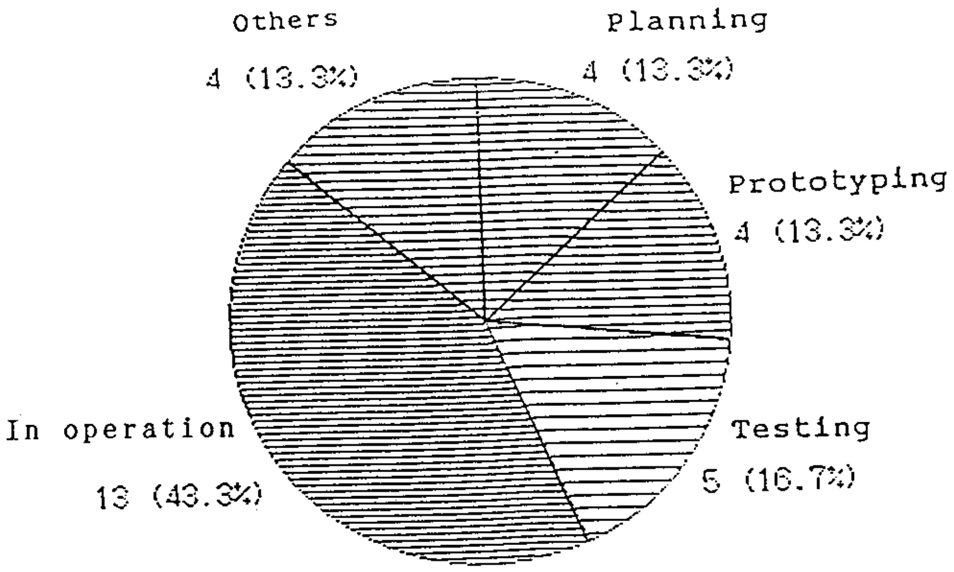

Figure 4-3 Levels of L-T-D analysis tool development in the various countries

Since 60% of the countries surveyed were found to be coping in some form with L-T-D, including the planning stage, and since 50% of projects under implementation have developed operational systems, the high interest placed on L-T-D by the various countries of the world and the importance of L-T-D can be perceived.

In the two sections that follow, the results of the survey relative to the simulation software for L-T-D and the simulator for L-T-D that had attained the operational stage the time of survey will be outlined.


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5. Simulation Software for L-T-D in Operation

Simulation software for L-T-D that had reached the operational stage at the time of study totaled seven as detailed below. The software included the simulation software for L-T-D EUROSTAG (Belgium, France, U.K.), intelligent system for L-T-D analysis (Czechoslovakia), STRALE (Italy), Y-method power system dynamics simulation program (Japan), simulation software for power system voltage collapse (Japan), ADCSIM2 (U.S.A.) and dynamic model of the power system behaviors (Yugoslavia). Data on these 7 simulation softwares, such as the functions, motivation/objective, system size, disturbance and future development time, are compiled in Tables 5-1, 2 and 3. The development objective in each case is a simulation of the transient behavior of the power system, and the system scale embodies several hundred generators and several thousand buses. Load models are static load models in most cases, while the network models consist entirely of π-type positive sequence models. External disturbances include loss of load, loss of generator and loss of transmission line.

Table 5-1 Simulation Software for L-T-D in Operation (As of May 1990)

Program / Simulator	Country	Developer	Development Period	Function	Motvation / Objective
(1) EUROSTAG	Belgium, France U.K.	TRACTEBEL EDF	1984 - 1989 1988 - 1989	General Purpose	Simulation of all the dymamics of a power system with exception of fast electromagnetic transients
(2) Intelligent System for L-T-D Analysis	Czechoslovakia	Power Research Institute	1983 -	General Purpose	After-the fact-analysis, Contingency Analysis, Drafting of countermeasures to the outage
(3) Digital Program : STRALE	Italy	ENEL	1984 - 1987	General Purpose	Consideration of detailed power system behaviour accounting for primary and secondary frequency control, secondary voltage control, OLTC's, boiler dynamics and all the other slow controls
(4) Y-Method Power System Dynamics Simulation Program	Japan	CRIEPI	1975 - 1985	General Purpose	Simulation of power system dynamics and phenomena such as power swing, frequency and voltage fluctuation power plant dynamics and so on in the time range of a few seconds to a few minutes
(5) Simulation Software for Power System Voltage Collapse	Japan	CRIEPI	- 1980 (Ver.1) 1987 - 1989 (Ver.2)	Problem Oriented	Simulation of power system dynamics and phenomena focussing on analysis of voltage stability in the time range up to tens of minutes
(6) AGCSIM2	U.S.A.	ECC Inc.	1987 - 1989 (Ver. 1) 1987 - 1991 (Ver. 2)	Problem Oriented	Synthesis and evaluation of AGC and of Var control
(7) Dynamic Model of the Power System Behaviors	Yugoslavia	Power System Institute SARAJEVO	1968 - 1978	Problem Oriented	Electrical Oscillation, dynamic stability problem, system protective relay testing, load scheduling, dispatcher training and education

note: — not available

Table 5-2 Simulation Software for L-T-D in Operation (As of May 1990)

Program / Simulator	Environment	System Size	Generator Model	Load Model	Network Model	Disturbance
(1) EUROSTAG	Workstation (APOLLO,SUN, VAX)	2000 buses, 200 generators 200 OLTs	Full Park 4 rotor winding model - saturation effect in both axes	Dynamic Load Model	π-type Positive Sequence Model	short-circuit, line and load switching, unit tripping and starting, controller set point changes, transformer tap change operations
(2) Intelligent System for L-T-D Analysis	EC 1034	800 buses, 300 transformers, 30 HVDC links 300 relays	—	—	—	load change, loss of load feeders, loss of generating plants, loss of transmission lines, reduction of generator output, loss of HVDC link
(3) Digital Program: STRALE	Workstation (APOLLO)	600 buses, 150 power stations	—	Static Load Model	π-type Positive Sequence Model	line opening or reclosing, unit tripping, load shedding or rescheduling, change of references and of parameters of regurations
(4) Y-Method Power System Dynamics Simulation Program	main frame computer (IBM, FACOM, HITAC)	1000 buses, 400 generators	Simplified Park's model	Static Load Model	π-type Positive Sequence Model	load change, loss of load feeders, loss of generator plants, change of generating plants, loss of transmission lines and so on.
(5) Simulation Software for Power System Voltage Collapse	main frame computer (IBM, FACOM, HITAC)	1000 buses, 400 generators	Simplified Park's model	Static Load Model	π-type Positive Sequence Model	load change, opening or reclosing of transmission lines
(6) AGCSIM2	VAX computer	no physical limit (direct function of available memory)	—	—	π-type Positive Sequence Model	loss of model, sudden load change loss of lines, frequency and voltage excursions
(7) Dynamic Model of the Power System Behaviors	VAX computer	80 buses, 12 generators 20 load models	Analog Model	—	—	any type of diturbances

note: — not available

Table 5-3 Simulation Software for L-T-D in Operation (As of May 1990)

Program / Simulator	Time Range	Simulation Technique Time Step	Integration Technique	Future Development Plan
(1) EUROSTAG	From 1 to 10000 sec.	From 0.001 to 100 sec.	Predictor - corector method	Algorithmics : treatments of very large system, Hardware : use of multiprocessor computers Network : unsymetric conditions, DC links, detailed topology of substations
(2) Intelligent System for L-T-D Analysis	up to 30 sec.	From 0.05 to 0.1 sec.	Euler method	Development of L-T-D expert system
(3) Digital Program : STRALE	From a few seconds to several minutes	From 0.5 to 1.0 sec.	Predictor - Corector method (2nd order explicit mothod)	None
(4) Y-Method Power System Dynamics Simulation Program	From a few seconds to a few minutes	0.01 sec. (typically)	Runge - Kutta (fixed time step)	None
(5) Simulation Software for Power System Voltage Collapse	From a few seconds to tens of minutes	From a few seconds to tens of seconds	Euler method	None
(6) AGCSIM2	up to 24 hours	1 sec.	Trapezoidal	Expansion of set of voltage control devices, Addition of model of thermal plant, lines and transformers, Addtion of graphics
(7) Dynamic Model of the Power System Behaviors	From 1 msec. to a few minutes	any time	—	Connection of the analog generator model to VAX computer

note: — not available

6. Simulator for L-T-D in Operation

Simulators for L-T-D that had attained the operational stage at the time of study totaled 4, including APSA (Japan), APOSS (Japan), TNS (Japan) and PPSS (Italy). The function, motivation/objective, system size, disturbance and future development time with respect to the 4 simulators are given in Tables 6-1, 2, and 3.

The four simulators have all been developed between the latter half of 1980s and early 1990s. The objectives of development broadly can be divided into analysis of dynamic behaviors of the power system and training of the system operators. However, as the simulator is hardware and is subject to physical limitations, the manageable system scales range from several to several tens of generators, which represent small fractions of the scales manageable with software. The network model with 2 simulators uses the analogue model to make possible more realistic simulations.

Table 6-1 Simulator for L-T-D in Operation (As of May 1990)

Program / Simulator	Country	Developer	Development Time	Function	Motvation / Objective
(1) Advanced Power System Analyzer (APSA) (Hybrid Simulator)	Japan	Kansai Electric Power Co. Ltd./ Fuji Electric Co. Ltd	1987 - 1989 and in further development	General purpose	Simulation of dynamic behaviour for a large scale power system in the time range of a few milliseconds to a few minutes
(2) Advanced Power System Simulator (APOSS) (Hybrid Simulator)	Japan	Hokuriku Electric Power Co. Ltd./ Toshiba Co. Ltd.	1988 - 1990	General purpose	Training of power system operators of the regional control center
(3) Transient Network Simulator (TNS) (Analog Simulator)	Japan	Fuji Electric Co. Ltd.	1980 - 1990 (1st stage) 1990 - 1995 (2nd stage)	Problem oriented	Development of prevention system for cascaded faults, Development and verification of system stabilization, Research for load characteristics and voltage instability, Development of verification of artificial intelligent system, Education and development of on-line simulation system
(4) Real-time prototype of power system simulator: PPSS(digital simulator)	Italy	ENEL -Research and Development Department- Automatica Reseach Center	1984 - 1986	Problem oriented	Operator training. Tool for the Control Center. Means to improve engineering understanding of power sysytem phenomena. Feasibility with regard to real-time performace, to power system size and to software/hardware costs.

Table 6-2 Simulator for L-T-D in Operation (As of May 1990)

Program / Simulator	Environment	System Size	Generator Model	Load Model	Network Model	Disturbance
(1) Advanced Power System Analyzer (APSA) (Hybrid Simulator)	main frame and EWS (HITAC M-660H, 2050/32)	30 generators, 60 transformers	Park's model	Dynamic Load Model	Analog Model	load change, load shedding, loaa of load, loss of load feeders
(2) Advanced Power System Simulator (APOSS) (Hybrid Simulator)	main frame computer (TOSBAC-G8090, 7/40E)	450 buses, 130 generators, 320 load points, 2 AGC areas, 181 relays	Simplified Park's model	Dynamic Load Model	π-type Positive Sequence Model	load change, loss of load feeders, loss of generating units, up/down of generator output, loss of transmission lines, loss of switching station and substation, 3-phase short accident
(3) Transient Network Simulator (TNS) (Analog Simulator)	—	6 generators, 7 load models, 2 SVCs, 3 V&VCs, 6 controllers	Detailed Park's model (three phase)	Dynamic Load Model	Analog Model	load change, loss of load feeders, loss of generator plants, change of generating plants, loss of transmission lines and so on.
(4) Real-time prototype of power system simulator: PPSS(digital simulator)	GOULD 32/27	70 busses, 15 power stations	Over/under excitation limiting circuits	Static load model	π - type positive sequence model	line opening or reclosing, unit tripping, load shedding or restorarion, change of reference and of paramaters of regulations.

note: — not available

Table 6-3 Simulator for L-T-D in Oepration (As of May 1990)

Program / Simulator	Simulation Technique		Integration Technique	Future Development Plan
	Time Range	Time Step		
(1) Advanced Power System Analyzer (APSA) (Hybrid Simulator)	From a few millisec. to tens of minutes	From a few seconds to tens of minutes	—	None
(2) Advanced Power System Simulator (APOSS) (Hybrid Simulator)	From a few millisec. to tens of minutes	100 msec. (transient stability computation)	Trapezoidal method	None
(3) Transient Network Simulator (TNS) (Analog Simulaor)	no limitation	10 msec. (AVR), 50 msec. (GOV) (sampling time)	—	Development of L-T-D program simulation, Development of on-line simulation system
(4) Real-time prototype of power system simulator: PPSS(digital simulator)	To tens of minutes	0.2 seconds	Euler explicit method	None

note: — not available

7. Concluding Remarks

1) Experience of major disturbances involved with LTD in various countries

It appears clearly that LTD phenomena can occur in any kind of system (large or small, weakly or strongly meshed, etc.). In cases where the initial disterbance involves tripping of equipment, the "engine" of the LTD consists of either overload of equipment (cascading tripping), or frequency deviation and/or voltage decline. There is equal probably of either occurring.

2) Needs and Objectives of the LTD tools

For the study of slow controls such as AGC, slow dynamic programs* are still used because in this case fast and/or rough phenomena are not considered.

It seems that there are no further developments on this kind of study tool.

Indeed the needs of a universal tool for completely studying LTD exist, but the problem is difficult. The chief difficulty is that slow and fast transients are mixed. As a consequence, during major disturbances, the real behavior of a system over a period of several minutes or tens of minutes cannot be simulated by means of a classical slow dynamic program which is not able to display possible fast electromechanical transients.

---

* A slow dynamic program takes into account the a.c. network algebraic equations and the mechanical unit differential equations assuming a linked rotor system.

Thus, several participants reported that they had developed or they were developing a new generation, universally applicable tool to study LTD.

The objectives of LTD studies are several: design of the system, tuning of controllers or protections, set up of operational procedures, understanding of phenomena, after-the-fact analysis of large disturbances and training.

3) Current status and perspective of LTD tools

As far as the new generation of tools is concerned, a lot of work is being done in many countries. We must notice that in Japan large hybrid simulators have been put in operation recently or are under development. These simulators are very sophisticated as far as the hardware is concerned. Some are able to simulate a wide range of phenomena, including those involving short time constants, because they simulate in the analog network the voltage and current waves. One advantage is the ability to obtain a real time simulation and perhaps the possibility of connecting actual equipment for testing purposes. The disadvantage is probably the cost and the inflexibility of the analog part. But other countries have adopted a full digital solution. Thus, we recommend that the SC 38 follow future developments in hybrid simulators.

In the digital solution, the general tendency is an extended frequency range of the system modelization: fast (typically rotor oscillations) and slow (typically boiler transients and centralized controls on active power or voltage) phenomena are represented. Progress has been made in "userfriendliness" : it is now possible to model some equipment without writing a code.

As far as the algorithms are concerned, some software uses alternatively a complete model (with fast and slow transients) and a simplified one (with only slow transients) according to the state of the system and employing two different fixed integration time steps: in such a case, particular attention is devoted to the linking between the two models and the switching criteria. Other software uses the same system representation during all the simulation. Most seem to use a fixed integration time step, which can be time consuming. However, one employs a step varying according to the behavior of the system, and to a predetermined precision, applying modern mathematical methods.

4) Other comments

There is ongoing research to overcome the limitations of the actual industrial software included in Dispatcher Training Simulators which are based on slow dynamic programs. In DTS in the modeling, real time simulation is mandatory. This necessitates some simplifications. But some of the developments made for LTD study tools are being applied to research work on DTS.

The work of this task force (TF 38.02.08) will be continued by actual simulation exercises done with several tools on a set of test systems. Thus we will be able to clarify the advantages/disadvantages of the different methodologies presently in use.


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Appendix <1>

Questionnaire on Long-Term Dynamics (L-T-D)
in Power Systems

QUESTIONNAIRE
ON
LONG-TERM DYNAMICS (L-T-D) IN POWER SYSTEMS
Prepared by TF 38.02/0.8, CIGRE

Part A: Experience of Major Disturbances involved with L-T-D in Various Countries

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Remark: In answering Question 1, please use one set of format (Format A) for each power system disturbance

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(QUESTION 1) Major Power System Disturbances involved with L-T-D in Various Countries

1-1. Have you had any large-scale/medium-scale power system outages involved with L-T-D in the past decade in your country ? Please check proper answer( ).

a ( ) YES
b ( ) NO
c ( ) Others [ ]

In case your answer is YES, please answer questions 1-2 to 5-3 in connection with the outage(s) experienced.

In case your answer is NO, please proceed to Question 2 in Part B.

1-2. With regard to the outage(s), please proceed with your answers in accordance with the items presented below.

a. Location of the outage(s) --- name of area, utility and country
b. Date of the outage(s) --- time of the day, day of the week, year
c. Features of the system structure at the outage(s)
d. Environmental condition prior to the occurrence of the outage(s) --- meteorological or natural phenomena
e. System condition prior to the occurrence of the outage(s) --- heavy load, maintenance of equipments, etc.
f. Primal cause of the outage(s) --- the initiating event, mal-operation, etc.
g. Chronographic transition of the outage(s) after the initiating event
h. Scale of the outage(s) --- area of the interrupted region, amount of the interrupted power supply(MW/MWh), the outage duration time, etc.
i. Impact to the community.

1-3. With regard to the cause of outage-spreading and to the control actions at the outage time, please proceed with your answers in accordance with the items presented below.

a. Actions or sequence of actions of the protective equipments
b. Actions or sequence of actions of the control equipments
c. Actions or sequence of actions of system operator
d. The major factor of the outage-spreading

1-4. With regard to post-outage countermeasures, please proceed with your answers in accordance with the items presented below.

a. What countermeasure did you take immediately after the occurrence of the outage(s)?
b. What did you take as a long-term countermeasure for preventing the similar outage(s)?
c. Do you have any plan in the future for preventing the similar outage(s)?

1-5. If any relevant papers, reports, etc. on the outage(s) are available, please let us be informed.

If possible, we would like to have copies enclosed.

Part B: Needs and Objectives of L-T-D Analysis

Remark: In answering Question 2, please use Format B

(Question 2) Objectives and Functions of L-T-D Analysis

2-1. How is L-T-D defined in your country (organization)?
[ ]

2-2. Has any L-T-D analytical program/simulator (including hybrid simulator) been developed in your country (organization)? Please select your answer from the items presented below.

a ( ) Developed.
b ( ) Under development.
c ( ) Development is being planned.
d ( ) Development is considered necessary, but there are no concrete development or development plans.
e ( ) Need for development is not felt.
f ( ) Others.
[ ]

2-3. For what objectives is the L-T-D analytical program/simulator used?

Please select your answers from the items listed below (multiple choice admitted).

a ( ) After - the fact - analysis
b ( ) Contingency analysis
c ( ) Drafting of countermeasures to the outage
d ( ) Operation planning
e ( ) System stabilizing control
f ( ) Others
[ ]

2-4. What are the major functions of L-T-D analysis? Please select items considered especially important from among those listed below (multiple choice admitted).

a (   ) to clarify the constitution of the system which brought the outage spreading
b (   ) to analyse the underlying mechanism of the outage spreading and to πc a cascade of outages after the initiating event
c (   ) to clarify the behavior of various plants (thermal, nuclear, hydro, etc.)
d (   ) to study the control scheme such as: overload releasing, generator tripping, load reduction by lowering voltages, system separation, load shedding, etc.
e (   ) to determine and coordinate the set point of frequency/overload relays
f (   ) to investigate the AGC operation performance for system stabilization
g (   ) to determine the necessary amount and the location of spinning reserve
h (   ) to develop the training simulator for L-T-D analysis
i (   ) others
[   ]

Part C: Current Status and Perspective of Analytical Tools

Remark: In the subsequent answers, please use <u>one set of format (Format C) for each program/project</u>.

(Question 3) The L-T-D Analytical Program/Simulator Developments and Development Schedules.

3-1. Name of the L-T-D analytical program/simulator or the project.

3-2. Name of the organization engaged in the development

3-3. Stage and time of the development

a. Stage of the development
[( )Planning, ( )Prototyping, ( )Testing, ( )Practical]
b. Date of commencement
[ ]
c. Date of completion
[ ]
d. Target year of completion
[ ]
e. Others
[ ]

3-4. Motivation and Objective of the L-T-D analytical program/simulator development

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

b. Structure and general flow of the program/simulator

c. Environment of the program/simulator

For example, please give answers to the items listed below.
(1) Computer used for the development.
(2) Computer used for practical operation.
(3) The operating system (OS).
(4) The program language.
(5) Necessary memory capacity.
(6) Others.

d. The scale of the test system that can be handled.

For example please answer this question in accordance with the item presented below.

(1) Number of buses --- generation and prime mover buses, load buses possible to be shed, voltage controlled load buses
(2) Number of load points
(3) Number of AGC areas
(4) Number of voltage and reactive power controllers (OLTC, Sh.C, Sh.R,etc.)
(5) Number of protective relays.

3-6. System components and models that can be handled.

How is each component represented (mathematical models and block diagrams)? Please refer to the following classifications.

a. Plant models
* Thermal plants
* Nuclear plants
* Hydro plants
* Gas turbines
* Others

b. Speed governor models
* Thermal plants
* Nuclear plants
* Hydro plants
* Gas turbines
* Others

c. Generator models
* Synchronous generators
* Induction generators
* Others

d. Excitation system models
* AVR
* PSS
* Others

e. Transmission system models
* Transmission lines (π type/T type, Positive sequence/Three phases, Detailed/Simplified, etc.)
* Tansformers
* Under excitation controller, Over excitation controller, Automatic reactive power regulator
* On-load tap changer, shunt capacitor, shunt reactor, static var compensator

f. Load models
  - * Static load characteristics
    - Voltage characteristics
    - Frequency characteristics
    - Voltage/Frequency characteristics
  - * Dynamic load characteristics
    - Induction motor
    - Others

g. Relay models
  - * Under-frequency load shedding
  - * Under-frequency unit trip
  - * Under-voltage load trip
  - * Under-voltage unit trip
  - * Loss-of-excitation unit trip
  - * Distance relays for line protection
  - * Others

h. Dispatch center / System stabilizing control model
  - * AGC (LFC & ELD)
  - * Voltage and reactive power control
  - * System Stabilizing controller
  - * Others

i. Others

[ ]

3-7. How is the dynamic characteristic of generator represented?

For example, please answer this question according to classifications given below.

a. Detailed Park's model / Swing equation for individual units
b. Simplified Park's model / Swing equation for individual units
c. Xd' model / Swing equation for individual units
d. Algebraic equation model for individual units and power flow computation
e. Uniform frequency model for all units (aggregate inertia) and power flow computation
f. Uniform frequency model for all units (aggregate inertia)
g. Others

[ ]

3-8. What method is used for load flow computation?

For example, please answer this question according to classifications given below.

a. Detailed power flow computation (AC model)
b. Linearized power flow computation (DC model)
c. Others
[ ]

And, how often is the load flow computation run in order to determine conditions on the network and to obtain the electrical loading on each of the generators.
[ ]

3-9. What sort of disturbances can be handled in the L-T-D program/simulator?

For example, please answer this question as given below.

a. Load change at buses
b. Loss of load feeders
c. Loss of generating plants
d. Reduction of generator outputs
e. Loss of transmission lines
f. Loss of switching station
g. Loss of substation
h. Scenario comprising the combination of such disturbances
i. Others
[ ]

3-10. Please tell us about the analytical technique used for simulation.

a. Simulation time range to be handled.
[ ]

b. Calculation time steps.
[ ]

c. Numerical integration technique (especially for enhancement of calculation efficiency).

For example,

(1) Runge-Kutta method (fixed/variable time step)
(2) Predictor-Corrector method (e.g. Milne method)
(3) Trapezoidal method
(4) Others
[ ]

d. Is model change during simulation possible?
[ ]

e. Up to what extent of frequency and voltage deviation is it possible to handle (saturation, limiter, etc.)?
[ ]

3-11. In simulation, how are the actions of the operator handled?
[ ]

3-12. What sort of information regarding L-T-D can be obtained from this program/simulator?

For example, please answer this question according to classifications given below.

a. Dynamic responses of power flow, voltage phase angle, frequency, etc.
b. Dynamic behavior of state variables in plants, such as steam flow, pressure, temperature, feed water.
c. Relays action
d. Action of controllers,
e. Intervention of system operators (decision making, mal-operation, etc.)
f. Others
[ ]

3-13. How do you initialize the L-T-D simulation program/simulator, namely the initial state of a power system ? However black start is excluded from the scope of this questionnaire.

3-14. What is this program/simulator's interface like?
[ ]

3-15. If any papers, reports, etc. related to this program/simulator are available, please list them.

If possible, we would like to have copies enclosed.

(Question 4) Application of the Developed Program/Simulator to Test Systems

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Note: The objective is to obtain the preliminary information on the test system to be used in the contest, which is planned in the second phase of the TF activity following the present survey.

Only the TF members are requested to answer question 4.

4-1. Structure, conditions and parameters of the test system.

4-2. Condition and scenario of the simulated Contingencies, the sequence of events, etc.

4-3. Simulation results on the test system

For example,

a. Dynamic responses of power flow, voltage phase angle, frequency, etc.
b. Dynamic behavior of state variables in steam plants, such as steam flow, pressure, temperature, feed water.
c. Relay action
d. Controller action
e. Intervention of system operators (decision making, mal-operation, etc.)
f. Others
[ ]

4-4. Consideration on application results

For example, accuracy, CPU time, etc.

4-5. Would you please show us the validation methods for the models qualification.
[ ]

(Question 5) Future Development/Improvement of the program/simulator

5-1. Problems to be solved in the application of the program/simulator.
[ ]

5-2. Points to be improved in the future.
[ ]

5-3. Future development plans or new projects.
[ ]

Thank you very much for your kind cooperation.

If you have any question on this questionnaire, please contact,

Yasuo TAMURA
Dept. of Electrical Engineering
Waseda University
3-4-1 Ohkubo, Shinjuku-ku
Tokyo 169 Japan
Fax 81-3-205-2615 (direct)
Tel 81-3-200-3097

Please return your answer to the same address no later than April 30, 1990.


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Appendix <2>

Relevant Formats for Reply to the Questionnaire

Format A Experience of Major Disturbances involved with L-T-D in Various Countries
(Part A)

(Format A-1/2)

(Question 1) Major Power System Disturbances involved with L-T-D in Various Countries

1-1. Experience of the outage(s)

a ( ) YES
b ( ) NO
c ( ) Others
[ ]

1-2. Outline of the outage(s)

a. Location of the outage(s)

b. Date of the outage(s)

c. System structure

d. Environmental condition

e. System condition

f. Primal cause

g. Chronographic transition

h. Scale of the outage(s)

i. Impact to the community

(Continued) (No. A1-)

(Format A-2/2)

1-3. Action of Equipments and Cause of outage-spreading

a. Actions of the protective equipments

b. Actions of the control equipments

c. Actions of system operator

d. The major factor of the outage spreading

1-4. Post-outage countermeasures

a. Immediate countermeasure

b. Long-term countermeasure

c. Plan in the future

1-5. List of reference(s)

Name of respondent(s), organization(s), country

[No. A2-]

Format B

Needs and Objectives of L-T-D Analysis
(Part B)

(Format B-1/1)

(Question 2) Objectives and Functions of L-T-D Analysis

2-1. Definition of Long Term Dynamics (L-T-D)

2-2. Development of L-T-D analytical program/simulator

a (   ) Developed.
b (   ) Under development.
c (   ) Development is being planned.
d (   ) Development is considered necessary, but there are no concrete development or development plans.
e (   ) Need for development is not felt.
f (   ) Others.
[   ]

2-3. Objectives of L-T-D analytical program/simulator

a (   ) After - the fact - analysis
b (   ) Contingency analysis
c (   ) Drafting of countermeasures to the outage
d (   ) Operation planning
e (   ) System stabilizing control
f (   ) Others
[   ]

2-4. Major functions of L-T-D analysis

a (   ) to clarify the constitution of the system which brought the outage spreading
b (   ) to analyse the underlying mechanism of the outage spreading and to ## a cascade of outages after the initiating event
c (   ) to clarify the behavior of various plants (thermal, nuclear, hydro, etc.)
d (   ) to study the control scheme such as overload releasing, generator, tripping, load reduction by lowering voltages, system separation, load shedding, etc.
e (   ) to determine and coordinate the set point of frequency/overload relays
f (   ) to investigate the AGC operation performance for system stabilization
g (   ) to determine the necessary amount and the location of spinning reserve
h (   ) to develop the training simulator for L-T-D analysis
i (   ) others
[   ]

Name of respondent(s), organization(s), country

[No. B1-   ]

Format C Current Status and Perspective of Analytical Tools
(Part C)

(Format C-1/7)

(Question 3) The L-T-D Analytical Program/Simulator Developments and Development Schedules.

3-1. Name of the project

3-2. Name of organization(s)

3-3. Stage and time of development

a. Stage of the development
[( )Planning, ( )Prototyping, ( )Testing, ( )Practical]

b. Date of commencement

c. Date of completion

d. Target year of completion

e. Others

3-4. Motviation and objective of the L-T-D analytic program/simulator development

(Continued) [No. C1-]

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

b. Structure and general flow of the program/simulator

< Extra sheets may be added, if necessary >

c. Environment of the program/simulator

d. Scale of the test system that can be handled

(Continued)

[No. C2-]

3-6. System components and models that can be handled.

‹ Extra sheets may be added, if necessary. ›

(Continued) (No. C3-)

3-7. Representation of generator dynamics

3-8. Method of load flow computation

3-9. Disturbance of that can be handeled

3-10. Analytical techniques for simulation

a. Simulation time range

b. Time steps

c. Numerical integration technique

d. Model change

e. Frequency / voltage deviation

(Continued)

[No. C4-]

(Format C-5)

3-11. How to handle or actions of the operator

3-12. Informations from the program/simulator

3-13. Initialization of the program/simulator

3-14. Interface of the program/simulator

3-15. List of the reference(s)

(Continued)

[No. C5-]

Format C

(Format C-6/7)

(Question 4) Application of the Developed Program/Simulator to Test Systems

4-1. Outline of the test system

4-2. Condition and scenario in the simulation

4-3. Simulation results

4-4. Consideration on the application results

4-5. Validation methods

(Continued) [No. C6-]

Format C

(Format C-7/7)

(Question 5) Future Development/Improvement

5-1. Problems to be solved in the application of the program/simulator

5-2. Points to be improved in the future

5-3. Future development plans or new projects

Name of respondent(s), organization(s), country

[No. C7-]

Appendix <3>

Simulation Software for L-T-D in Operation

Program (1)	EUROSTAG (EDF/TRACTEBEL)
Program (2)	Intelligent System for L-T-D Analysis (PRI)
Program (3)	Digital Program: STRALE(ENEL)
Program (4)	Y-Method Power System Dynamics Simulation Program (CRIEPI)
Program (5)	AGCSTM2 (ECC)
Program (6)	Dynamic Model of the Power System Behaviors (PSI)

Program(1) EUROSTAG

France C-1 (EDF/TRACTEBEL) (Format C)

Current Status and Perspective of Analytical Tools

3-1. Name of the project

EUROSTAG

3-2. Name of organization(s)

TRACTEBEL
ELECTRICITE DE FRANCE

3-3. Stage and time of development

a. Stage of the development

[( )Planning, ( )Prototyping, ( )Testing, (X)Practical]

b. Date of commencement

1984

c. Date of completion

1989

d. Target year of completion

----

e. Other

3-4. Motivation and objective of the L-T-D analytic program/simulator development

To have a tool able to simulate all the dynamics of a power system with exception of fast electromagnetic transients. This single tool is able to simulate with accuracy the behavior of the system during a period of time ranging from a few seconds up to several hours. It takes takes into account the phenomena ranging from electromechanical rotor oscillations to very slow boiler dynamics or to the load increase.

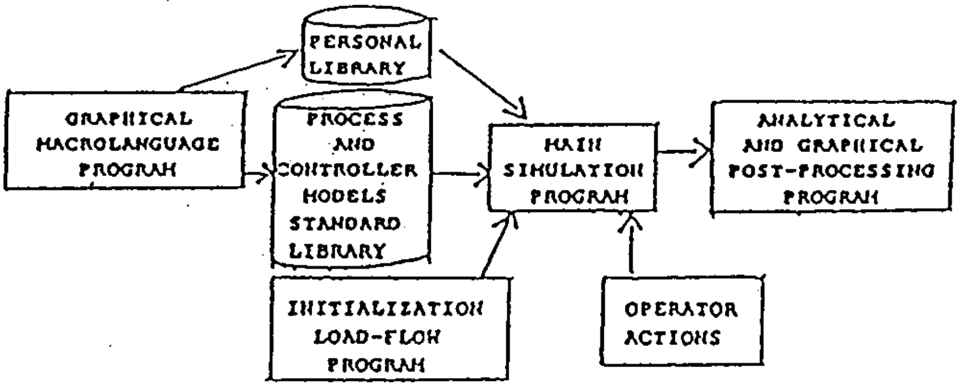
This single tool replaces the transient stability and the long-term stability programs, avoids the gap between transient and long-term simulations, allows to observe the complete recovery of steady state condition after a disturbance and suppress the need of successive initialization calculations when simulating behaviors with alternans of fast and slow dynamics.

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

- The integration step varies continuously and automatically, ensuring constant calculation accuracy whatever the speed of the excited phenomena.
- The algebraic equations are solved simultaneously in the correction phase of the integration algorithm.
- An appropriate management of the numerous discontinuities appearing in process and controller models allows a smooth variation of the stepsize.
- A graphical simulation macrolanguage allows the user the greatest freedom as regards the definition of his own models.
- Various operations can be initiated, as the simulation is running, through operator actions.

b. Structure and general flow of the program/simulator



c. Environment of the program/simulator

(1) WORKSTATIONS (APOLLO, SUN, VAX)
(2) WORKSTATIONS (H.P., APOLLO, SUN, VAX) + CRAY, IBM AND VAX mainframe connected to workstations
(3) UNIX and VMS
(4) FORTRAN
(5) Min. 8 MB CORE MEMORY

<u>COMMENTS</u> : The development has been done with the help of an engineering software tool.

d. Scale of the test system that can be handled

Number of buses :	2000
Number of generator :	200
Number of induction motors :	200
Number of load buses possible to be shed :	2000
Number of load buses :	2000
Number of dynamic load buses :	200
Number of AGC or AVC areas :	no limit
Number of OLTC :	200
Number of Sh. C. :	no limit
Number of Sh. R. :	no limit
Number of S.V.C. :	200
Number of protection relays	no limit
TOTAL NUMBER OF STATE VARIABLE :	5000

3-6. System components and models that can be handled.

Preliminary remark

The macrolanguage of EUROSTAG allows the user to build his own library of process an controller models. The user of EUROSTAG can also use standard libraries of classical models (for instance IEEE models), that are easy to code with the help of the macrolanguage.

The modelization of the units is very flexible by creating aggregates of "macroblocks", each device of the unit being coded separately (turbine, governor, bypass, AVR, ...).

See papers in reference.

a) PLANT MODELS : through macrolanguage

b) SPEED GOVERNOR MODEL : through macrolanguage

c) GENERATOR MODEL :

Synchronous : Full Park 4 rotor winding model- saturation effect in both axes.
Induction : see induction motor model.

d) EXCITATION SYSTEM MODEL : through macrolanguage

e) TRANSMISSION SYSTEM MODELS :

Lines :

- Π-type positive sequence model with dependency to frequency. Three phase model in progress.
- Transformers : off-nominal model with O.L.T.C. Leakage reactance depends on tap position.
- Under excitation controller, over excitation controller, automatic reactive power regulator are modelled through macrolanguge as s part the AVR system.
- O.L.T.C. : modelled through operator action or through specific automation model if automatic.
- Shunt capacitor, shunt reactor : as switchable impedances.
- Static Var Compensator : By means of the macrolanguage, the SVC and its controller dynamics can be modelized at the users' level.

f) LOAD MODELS

- Static load characteristics

$$P = Po \left| \frac{V}{Vo} \right|^{\alpha} \left| \frac{f}{fo} \right|^{\gamma}$$

$$Q = Qo \left| \frac{V}{Vo} \right|^{\beta} \left| \frac{f}{fo} \right|^{\gamma}$$

Active and reactive loads are sensitive to the voltage and the frequency.

- Dynamic load characteristics
  - Induction motors: simplified model : no rotor transients (1 state variable model)
  - full 2 cage rotor model (5 state variable models)
  - P(t) + jQ(t) : Active and reactive parts of the load can be the output of a transfer function or any block-diagram coded by means of the macro-language.

g) RELAYS MODELS

A library of relay models has been developed for specific applications :

- over- and under-frequency relays
- under-voltage relays
- overload relays
- impedance relays
- loss-of-synchronism relays for use on generators or for automatic separation of sub-systems.

h) DISPATCHER CENTER (System Stabilizing Control Model)

AGC and secondary voltage control has been modelled.

3-7. Representation of generator dynamics

See 3.7.c.

3-8. Method of load flow computation

A detailed power flow computation is used. The complex admittance matrix formulation is solved at each step, simultaneously, in the correction phase of the integration algorithm.

3-9. Disturbance of that can be handled

- short-circuit
- closing and opening of lines (including separation of synchronization of sub-systems).
- start-up of induction motors
- switching loads on and off
- transformer tap changer operations
- controller set-point changes
- any combination of the former disturbances

3-10. Analytical techniques for simulation

a. Simulation time range

From 1 to 10000 s.

b. Time steps

From about 0.001 to 100 s.

c. Numerical integration technique

Predictor-corrector method with variable stepsize and control of truncation error.
Simultaneously resolution of algebraic equations.

d. Model change

No model changes are possible during the simulation. The full modelization is used for fast or slow dynamics.

e. Frequency / voltage deviation

Up to the operation of the protection devices.

3-11. How to handle or actions of operator

The program looks like an interactive simulator. The interactive graphic display of variables during the integration process allows the operator to take the decision applying an operation (a disturbance) to system. He can interrupt the integration process, order the operation and restart the calculation as many times he wants. Another possibility is a batch simulation where the operator actions are described in a file, before running the simulation.

3-12. Information from the program/simulator

The use of post-processing allows the graphical display and printing of any state variables. The computation of this quantities is made interactively, at the request of operator. As an example, points a) to e) of proposed classification are obtainable.

3-13. Initialization of program/simulator

Steady state conditions before the L.T.D simulation are determined by means of load flow calculation, and, if necessary, by interactive operations on the simulated system and after complete damping of the related disturbances.

3-14. Interface of program/simulator

The program is normally run on a workstation allowing flexible and user-friendly dialog with the operator. When used in batch in mainframes, the result files area transferred on workstations to allow the use of post-processing program.

3-15. List of the reference(s)

STUBBE M., A.BIHAIN, J.DEUSE AND J.C.BADDER (1988).
"STAG - A new unified software program for the study of dynamic behaviour of electrical power systems", 88 WM 213-1, New York.

STUBBE M., A.BIHAIN, J.C.BADDER AND J.DEUSE (1988).
"Simulation of dynamic behaviour of electrical power systems in short- and long-term" CIGRE, Paris. Paper No.38-03.

Application of the Developed Program/Simulator to Test Systems

4-1. Outline of the test system

The proposed test system has been presented during the TF 38-02/08 meeting in Brussels, on 27th February 1990. Please refer to the paper submitted at that occasion.

4-2. Condition and scenario in the simulation

4-3. Simulation results

4-4. Consideration on the application result

4-5. Validation methods

Future Development/Improvement

5-1.Problems to be solved on the application of the program/simulator

----

5-2. Points to be improved in the future

5-3. Future development plans or new projects

ALGORITHMICS
- Treatments of very large systems (more than 3,000 nodes)
- Extension to faster phenomena

HARDWARE
- Use of multiprocessor computers

PROCESS AND CONTROLLER MODELS
- Set-up of a standard library if AVR, turbines, boilers and SVC models.
- Set-up of standard library of automatons : protection relays, tap changers ;...

USER FRIENDLINESS
- Graphical display of network diagram, and assisted data entry.

NETWORK
- Unsymmetrical conditions
- Detailed topology of substations
- DC links

Name of respondent(s), organization(s), country

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TRACTABEL
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Czechoslovakia C-1 (PR1) (Format C)

Current Status and Perspective of Analytical Tools

3-1. Name of the project

Intelligent System for L-T-D analysis

3-2. Name of organization(s)

Power Research Institute, Brno, Czechoslovakia

3-3. Stage and time of development

a. Stage of the development

[( )Planning, ( )Prototyping, (X)Testing, ( )Practical]

b. Date of commencement

Partly in 1983, 1986

c. Date of completion

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d. Target year of completion

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e. Other

Blocks of program are gradually developed according to he practical requests.

3-4. Motivation and objective of the L-T-D analytic program/simulator development

Motivation: Great number of outages in IPS during the years 1980-1986
Objective : After-The fact-Analysis
Contingency Analysis
Drafting of countermeasures to the outage

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

Calculations of load flows including the load voltage and frequency characteristics. Calculations of voltage and frequency stability. Transient stability calculations for voltage collapse and asynchronous operation analysis.

b. Structure and general flow of the program/simulator

Program for load flow analysis utilizing both Newton-Raphson and Gauss-Seidel methods.
Expert system for power transfer capability and voltage stability analysis.
Program for frequency stability analysis.
Program for transient stability analysis.

c. Environment of the program/simulator

(1) Computer used for the development:EC 1034 (compatible with IBM/370) PC AT
(2) Computer used for practical operation: EC 1034
(3) The operating System: VM/370-CMS
(4) The program language: FORTRAN 77, PASCAL
(5) Necessary memory capacity: 550-600 KB

d. Scale of the test system that can be handled

(1) Load flow, power transfer capability and voltage stability programs :
Maximum number of buses (generators and loads) is 1000,
Maximum number of branches is 1600 from which 200 transformers can be simulated.
The voltage control is possible in rack generator.
Static reactive power controllers can be simulated in every node.

(2)Transient stability program:
The scale of the system is 800 buses, 1200 branches, 300 transformers, 300 protective relays 30 HVDC links.

3-6. System components and models that can be handled.

The computer program for stability calculation is described in enclosed report, "Effect of the HVDC control on resynchronization of near-connected turbine-generators.

3-7. Representation of generator dynamics

See the same reference as in 3-6.

3-8. Method of load flow computation

Detailed power flow computation (AC model).
One solution has from 6 to 12 iterations.

3-9. Disturbance of that can be handled

a. Load changes at buses
b. Loss of load feeders
c. Loss of generating plants
d. Reduction of generator outputs
e. Loss of transmission lines
f. Loss of switching station
g. Loss of substation
h. Loss of electrical areas (islands operation)
i. Loss of HVDC links
j. Change of power transfer capability of HVDC links

3-10. Analytical techniques for simulation

a. Simulation time range

Load flow and power transfer capability programs enable simulations with long time range of hours.
The transient stability program is utilized for time range up to 30 s.

b. Time steps

Time step of transient stability calculation is 0.05 - 0.1 s.

c. Numerical integration technique

Euler Method

d. Model change

Model can be changed before simulation

e. Frequency / voltage deviation

Even asynchronous operation can be simulated.

3-11. How to handle or actions of operator

The operator actions may be handled in the load flow program. The actions include the secondary control of active power, switching the elements of Power System, reactive power control and pumped-storage plant operation,

3-12. Information from the program/simulator

Dynamic responses of power flows, voltage phase angles, swing curves, relays actions, action of controllers, HVDC links operation and intervention of system operators.

3-13. Initialization of program/simulator

The L-T-D simulation is initialized from normal power system operation.

3-14. Interface of program/simulator

The interface between program and user includes monitors, printers, terminals.

3-15. List of the reference(s)

M.Rusnak, V.Vyskocil, F.Kozak, P.Pavlinec
Effect of the HVDC control on resynchronization of near-connected turbine generators.
EP/SEM.10R.20; UN ECE Seminar on HVDC techniques, Stockholm, Sweden, May 6-9, 198

Application of the Developed Program/Simulator to Test Systems

4-1. Outline of the test system

4-2. Condition and scenario in the simulation

4-3. Simulation results

4-4. Consideration on the application result

4-5. Validation methods

Future Development/Improvement

5-1. Problems to be solved on the application of the program/simulator

Automatization of calculations and utilization for real-time analysis in dispatch center.

5-2. Points to be improved in the future

Model of generators, model change during simulation, improving the interface (graphic, automatic results proceeding).

5-3. Future development plans or new projects

Development of L-T-D expert system.

Name of respondent(s), organization(s), country

Messrs F.Kozak, P.Pavlinec, P.Modlitba
Power research Institute Brno Czechoslovakia

Program(3) Digital Program: STRALE

Italy C-1 (ENEL) (Format C)

Current Status and Perspective of Analytical Tools

3-1. Name of the project

Digital Programs: STRALE

3-2. Name of organization(s)

ENEL

3-3. Stage and time of development

a. Stage of the development

[( )Planning, ( )Prototyping, ( )Testing, (X)Practical]

b. Date of commencement

1.1.1984

c. Date of completion

31.12.1987

d. Target year of completion

-----

e. Other

3-4. Motivation and objective of the L-T-D analytic program/simulator development

In the past, a simplified long-term dynamic modeling was considered by ENEL (implemented in the simulation code named FREMED), based on the following :

- The electromechanical oscillations between generators were neglected only the mean frequency transients were considered.
- The network structure (lines, transformers, busbars,...) was neglected too: as consequence, information concerning bus voltages, line currents and power flows was completely lacking.
- The representation of primary frequency control, of supply systems and of prime movers was very simplified and referred only to the first time instants response after a perturbation. Besides, the various network units were ground into some "equivalent units" even if with a certain degree of detail (hydro, thermal, gas turbine, constant power).
- All the other slow controls, both of continuous type as the load-frequency regulation, and of discontinuous one as the protection, were not modelled with the exception of automatic load-shedding devices. They were represented by a single equivalent load-shedder, approximately accounting for all the true equipment installed in the system.

In the last years, the presence of new power system controls, as the secondly voltage regulation, together with a better knowledge of system phenomena and slow controls behaviour and with the occurrence of widespread and complicated incidents in the ENEL power system have put into evidence the need to improve the long-term dynamic modelling and the relevant simulation code, by respect to the above-mentioned simplified representation. It is nevertheless interesting to remark that the latter remains effective, with a very good accuracy degree, if the problem to be considered is only that of designing or verifying an automatic load-shedding plan (based on frequency or on frequency and its time derivative).

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

STRALE can simulate network aving 1000 buses and 200 power stations and associated controls.

b. Structure and general flow of the program/simulator

The software of STRALE consists of a package of three main programs (see Fig.1). The first program checks the input data, initialized the state variables and organizes all the data in a structured data-base. A part of input data, that is the network parameters and the steady-state values of the network variables, is automatically prepared through a standard load-flow program. The remaining data, that is the set of data relevant to the dynamic models are manually prepared by standard editor program.The second program accepts directives to perform simulation and to store the results on an output file. It implements the models of the network, of the thermal and hydro units, of the frequency/power and of the secondary voltage regulators, of the load-shedding and of the secondary voltage regulators, of the load-shedding devices, of the tap changers under load, and so on. It also manages disturbances that cause the network separation in two or more parts. This program accepts directive (by commands) from the terminal keyboard in order

- to introduce disturbances, as unit tripping, lines opening and closing, load disconnection, and so on,
- to insert some manual controls, as changing the set-point values,
- to perform a batch simulation during a given time interval (see extra sheet)

c. Environment of the program/simulator

STRALE is written in Fortran language and runs on APOLLO Domain Workstation.

d. Scale of the test system that can be handled

Usually, a part or the complete ENEL HV network (about 600 bused 150 power stations)

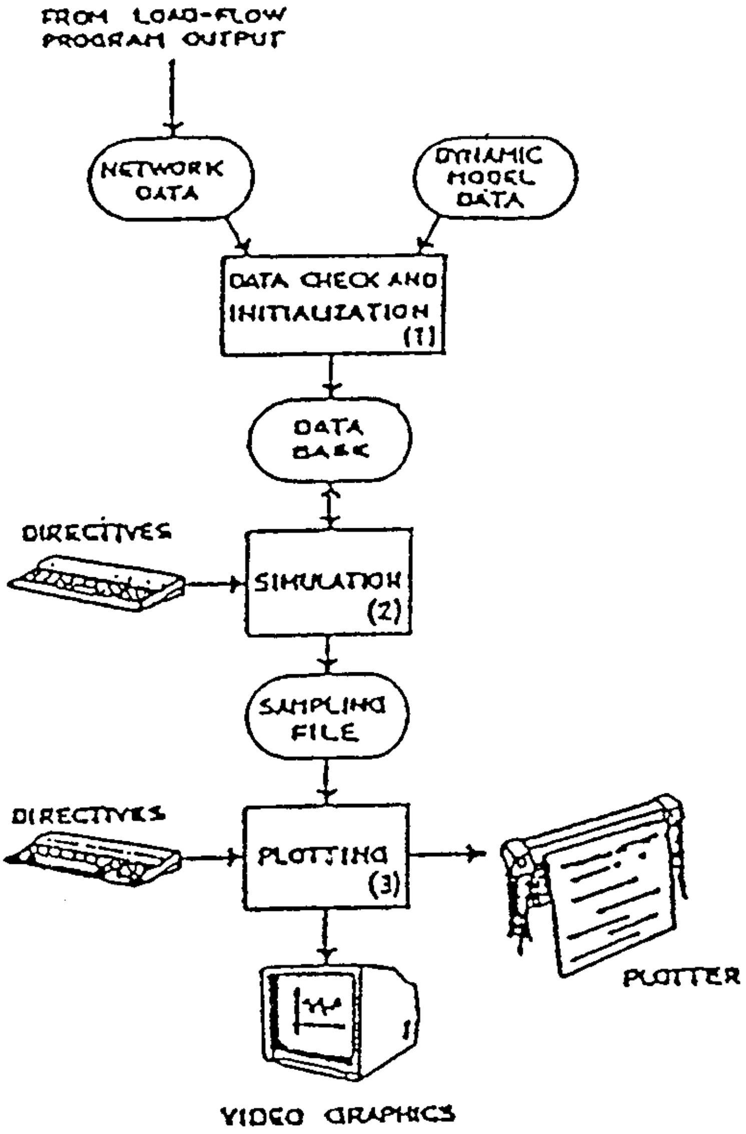


Figure 1 : STRALE Architecture

3-6. System components and models that can be handled.

Since all the phenomena listed in the point 2.1 are sufficiently slower than those associated with oscillations between the rotors of the various generators (electromechanical oscillations), it is possible to assume that the speed is the same for all the units of a connected network (mean frequency concept), as in the above-mentioned simplified modelling. More generally, it may be assumed that both the electromechanical transients are neglected, and therefore, in particular, both the electromechanical oscillations and the relative rapid dynamics of the primary voltage control loops are so as well.

The hypothesis that the speed is the same for all the units is equivalent as saying that there exists one single rotor that rotates at the average speed (or the mean frequency $f_m = \Omega_m / 2\pi$),as if the network had only one machine. Consequently the rotor angles of various machines no longer have any significance, and each generator is described by just one differential equation in respect of mechanical equilibrium

$$p\,\Omega_m = \frac{1}{M_h}(P_{mh} - P_{eh}) \qquad (1)$$

(h=1,..., n) if there are n alternators present). Pmh, Peh, Mn are the mechanical power, the delivered active electrical power, and the inertia coefficient of any alternator, respectively while p stands for the derivation operator with regard to time (p = d/dt), or 1/p represents the integration operator.

The assumption that the dynamics of the primary voltage control loops is neglected is equivalent to assuming that the voltage v at the terminals of each generator is practically the same as the reference voltage regulator, unless there be a compound: thus the electrical parts of the unit (i.e. the amplitudes of the internal e.m.f.s.) disappear. The terminal voltage of a group will therefore be variable only if Vref varies, that is in the case of the operation of over/under- excitation limiting circuits or to the action of secondary voltage regulation.

Main regulations

As regards the various regulations, Fig.2 and 3 show, in qualitative terms, the main ones: the frequency and active power control of thermal and hydro units, the voltage regulation of a generic unit which may be submitted to the secondary voltage control of a given network area. Without going into too much detail, it is nevertheless interesting to observe the following.

a) For frequency control

- The model of thermal units takes into account the frequency bias, the speed governor, the power regulator, the boiler and the superheater, the boiler controls, the value control, the MP and MP-LP stages of the turbine, several non-linearities. The power reference (Pref) can be imposed locally, through the load-programmer, or else originate from the network regulator (level signal of the load-frequency control).
- The boiler controls are not all those present, but only the faster ones from the point of view of the thermal process; that is those that may have the greatest effect on the network quantities behaviour; in practice, the admission steam pressure regulation and the firing (or air/fuel and water supply) controls.
- The representation of hydro units includes several types of speed governors (old and modern solutions, with temporary droop, with accelerometer, electrohydraulic regulators) ; the upper and lower limits on the needle servomotor and the deflector action for Pelton turbines; the efficiency as a suitable algebraic function of gate ratio, water head and speed (based on typical hill diagrams) for Francis turbines; several non linearities (mainly due to steady-state characteristics).

b) For voltage control

- The steady-state operation inside the over/under-excitation limits is ensured by the presence of the limiting circuits (the computation of the limit excitation current i also takes into account the magnetic saturations of the alternator), if the unit is no submitted to the secondary voltage control.
- Conversely, if the unit takes part in this regulation, the explicit representation of limiting circuits becomes superfluous, inasmuch as the static characteristics between the reactive power level ql of the area and the reactive power regulator reference qref of the unit is limited by the maximum values (qmax and qmin) of its deliverable reactive power. These limit power,which are variable depending on the operating point, are calculated on the basis of suitable algebraic expressions, accounting for magnetic saturations,in terms of the terminal voltage v and of the active electrical power Pe delivered by the unit.

Overall model

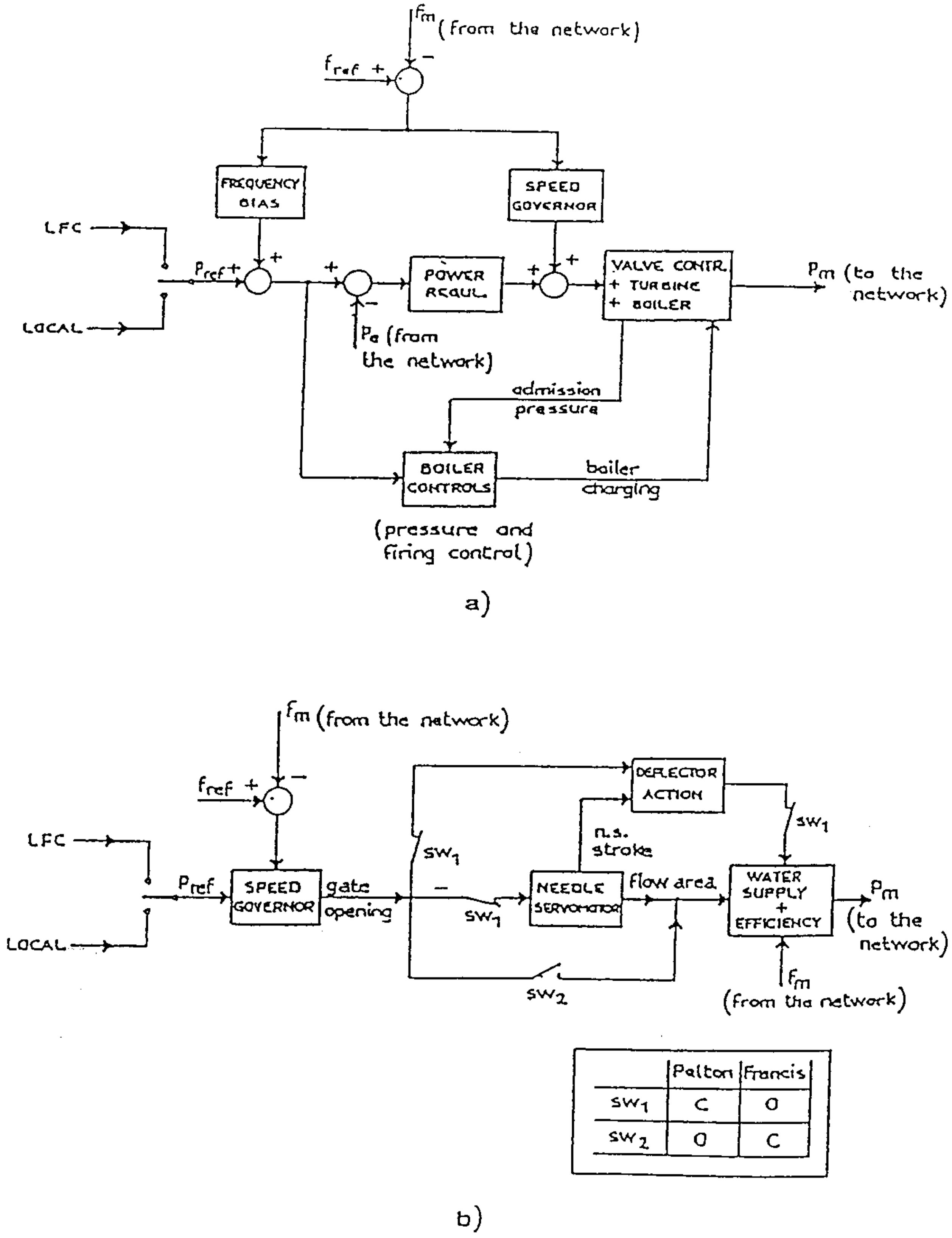
First of all , it seems worthwhile to note that

- The dynamic order of the models concerning the frequency and active power regulation (see Fig.2) is, at most, equal to 10.
- The dynamic order of the model depicted in Fig.3 is very low, inasmuch as both the secondary regulator of each area (which has, as its input, the difference between the reference vp'ref of the pilot node in that area and the actual voltage vp), the reactive power regulator of a group, and the limiting circuits are each described by a single differential equation of the 1st order.
- The models of the other control equipment (load-frequency regulators and voltage regulators of the on-load tap-changers) are even simpler.

The overall non-linear model of the electric power system for the simulation of slow dynamic behaviour can then be made to correspond to correspond to the qualitative block diagram depicted in Fig.4, in which the meaning of the vectors is the following

[Vl] voltages of the pilot nodes of the secondary voltage regulation and of the nodes with on-load tap-changers,
[Pg] active powers generated by the units,
[Qg] reactive powers generated by the units,
[Vg] voltage at the unit-terminals,
[m] transformation ratios of the on-load tap-changers,
[Pm] mechanical powers of the units,
[Pt] active power flows controlled by the secondary frequency regulation.

Figure 4 shows clearly two domains: that of the frequency and that of the voltage, which interact through the network.



	Pelton	Francis
sw_1	C	O
sw_2	O	C

Figure 2 : Qualitative block diagrams of the frequency and active power control of thermal (a) and hydro (b) units

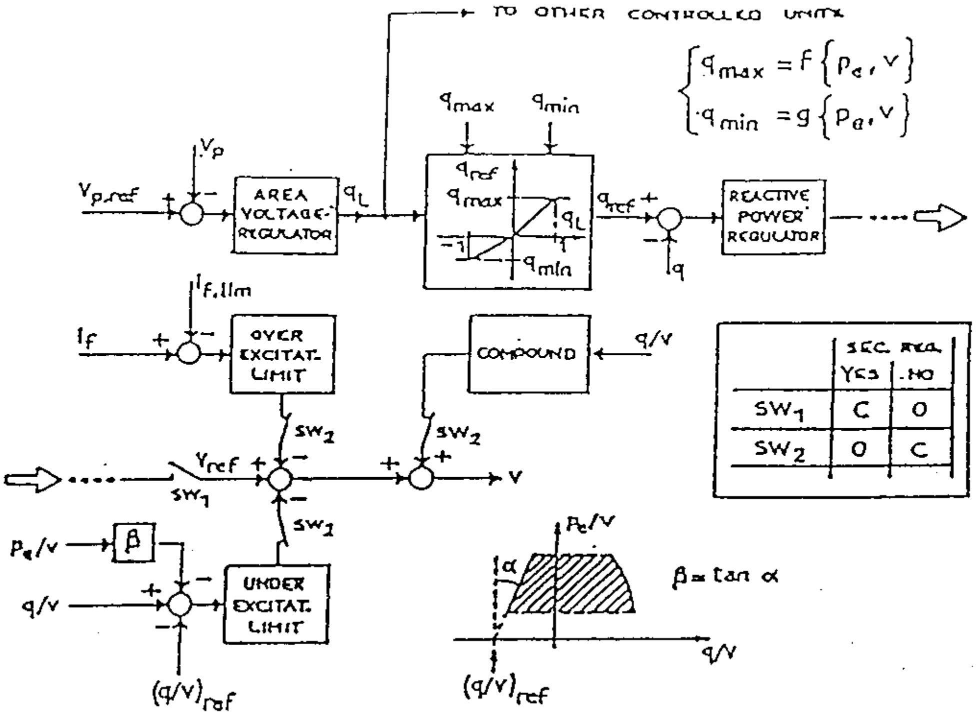


Figure 3 : Qualitative block diagram of the voltage control of each unit

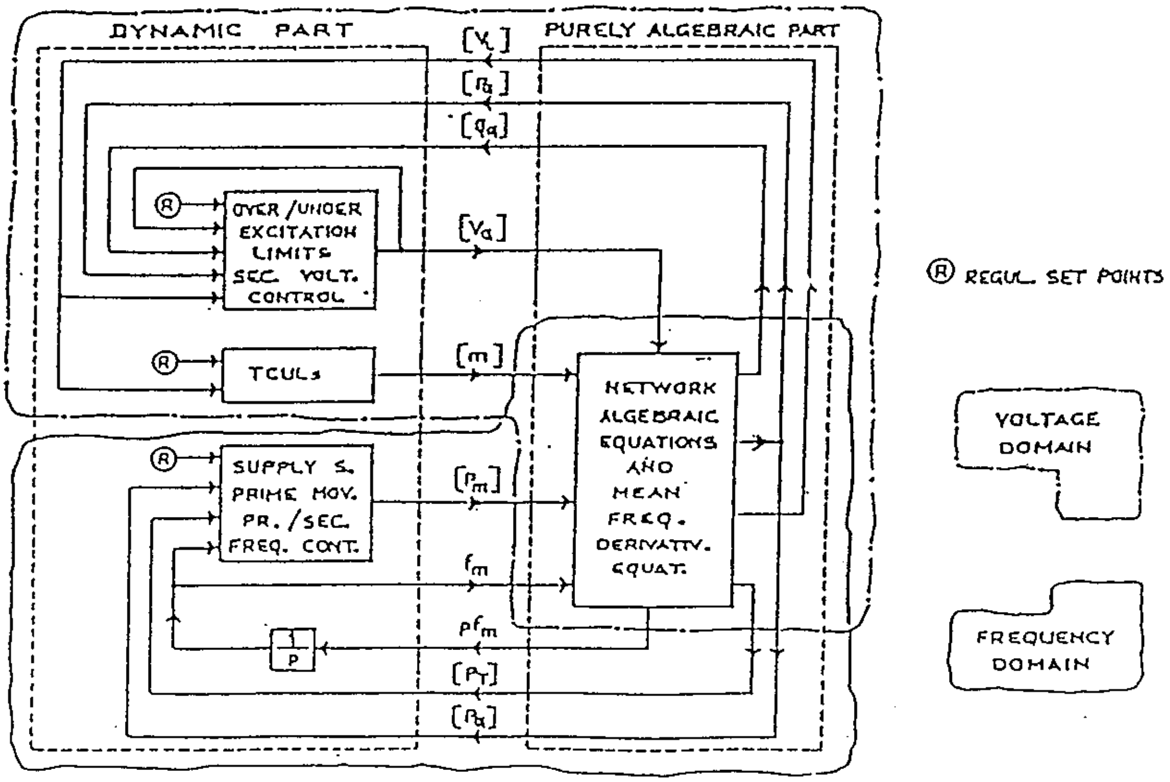


Figure 4 : Qualitative block diagram of the overall power system model

3-7. Representation of generator dynamics

Already described in 3-6.

3-8. Method of load flow computation

The method for solving the non-linear algebraic equations of the network and that one related to the mean frequency derivative represents an extension of the STOTT's method accounting for the equation of the mean frequency derivative. More precisely, there are three decoupled systems of equations: active power and voltage phases, reactive powers and voltage amplitudes, mean frequency derivative. In particular, the last one consists of a number of equations equal to the number of network separated parts. The Jacobian matrices are constant during the simulation until a perturbation happens that modifies the network topology. The algebraic equation systems are solved by a classical UL factorization method of sparse matrices.

3-9. Disturbance of that can be handled

- Lines opening or reclosing
- Units tripping
- Load-shedding or restoration
- Change of references and of parameters of regulations

3-10. Analytical techniques for simulation

a. Simulation time range

From few seconds to several minutes

b. Time steps

0.5 - 1 second

c. Numerical integration technique

2nd order explicit predictor-corrector method

d. Model change

e. Frequency / voltage deviation

46-54 Hz: 0.7-1.3 kv p.u.

3-11. How to handle or actions of operator

Manually by the run instructions

3-12. Information from the program/simulator

Tables and plotting

3-13. Initialization of program/simulator

3-14. Interface of program/simulator

STRALE is automatically connected to ENEL load-flow program in order to have the necessary initialization.

3-15. List of the reference(s)

[1] Baratella, P., and co-workers (1988). Recent and sophisticated developments of long-term dynamic modelling for the reconstruction of real incidents in the ENEL power system.
Proceedings of IFAC Symposium on Power System, Modelling and Control Applications, Brussels, September 1988.

[2] Arcidiacono, V., and co-workers (1979). On line detection and recording of major disturbance in the ENEL power system.
Proceedings of the 1979 PICA Conference, pp.273-283.

[3] Arcidiacono, V., (1983). Automatic voltage and reactive power control in transmission system.
Proceedings of the CIGRE-IFAC Symposium 39-83, Florence 1983, Survey Paper E.

[4] Arcidiacono, V., and S.Corsi (1985).Secondary voltage control at ENEL. Report prepared for GEGB/EDF/ENEL Collaboration WG 1/1, November 1985.

[5] Baratella,P., and co-workers (1981). The package of ENEL digital programs for off-line dynamic security studies. Proceedings of the Seventh PSCC, Lausanne 1981,pp.922-923.

[6] Colombo, F., and co-workers (1983). Considerations upon the representation of turbine and boiler in the dynamic response of fossil fired electrical units. Proceedings of the CIGRE-IFAC Symposium 39-83, Florence 1983, paper N. 310-05.

[7] EPRI (1974). Long Term Power System Dynamics. Vol.1. Summary and technical report.
EPRI 90-7-0, Final Report, June 1974.

[8] EPRI (1975). Long Term System Dynamics. Hybrid Simulation.
EPRI 908-1, Final Report, May 1975.

[9] EPRI (1977). Long Term Power System Dynamics. Phase II.
EPRI EL-367,Project 764-1, Final Report, February 1977.

[10] Ferrai, E., (1982). Block diagrams and typical transfer functions of turbine speed regulating systems. Report of CIGRE WG 31/32-03, November 1982.

[11] Marconato, R.,(1984/85). Sistemi electtrici di potenza, Vol.I and II. Cooperativa Libraria del Politecnico di Milano, CLUP, Milano.

[12] Quaxza, g., and E. Ferrari (1972). Role of power station control in overall system operation. In E. Handschin (ED.).
Real time control of electric power systems. Elsevier Publishing Company, Amsterdam -London-New York. pp.215-257.

Application of the Developed Program/Simulator to Test Systems

4-1. Outline of the teat system

See point 3-5.d

4-2. Condition and scenario in the simulation

Network splitting inside ENEL system

4-3. Simulation results

Very good agreement with the experimental recordings made by the HIPES system described in ref.2 of the 3-14.

4-4. Consideration on the application result

1) Some changes in the setting of load-shedders
2) Some variations in the regulation of thermal units

4-5. Validation methods

A system of relatively small dimension (20 busses, 5 power stations) but having the possibility to put into evidence all the phenomena associated to LTD.

Future Development/Improvement

5-1.Problems to be solved on the application of the program/simulator

None

5-2. Points to be improved in the future

Modelling of the several regulations of the thermal units.

5-3. Future development plans or new projects

None

Name of respondent(s), organization(s), country

Dr.Roberto Marconato, ENEL - Automatica Research Centre, Italy

Program(4) Y-Method Power System Dynamics Simulation Program

(Format C)

Current Status and Perspective of Analytical Tools

3-1. Name of the project

Y-Method Power System Dynamics Simulation Program

3-2. Name of organization(s)

Central Research Institute of Electric Power Industry (CRIEPI)

3-3. Stage and time of development

a. Stage of the development

[( )Planning, ( )Prototyping, ( )Testing, (X)Practical]

b. Date of commencement

1975

c. Date of completion

1985

d. Target year of completion

----

e. Other

3-4. Motivation and objective of the L-T-D analytic program/simulator development

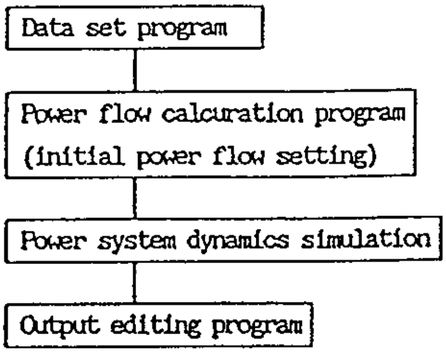
The objective of this program are to simulate as possibly as precisely power system dynamics and phenomena such as power swing, frequency, and voltage fluctuation, power plant dynamics, and so on in the time range of a few seconds to a few minutes and to utilize for power system planning, operation, and development of new type machines, equipments, control systems, and so on.

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

Corresponding to the objective, the sufficiently detailed models of the elements in power system are used in this program.

b. Structure and general flow of the program/simulator



c. Environment of the program/simulator

In the almost all large computer system
(IBM, FACOM, HITAC, and so on)

d. Scale of the test system that can be handled

generator:400, bus:1000, branch:1200 (1.8MB)

3-6. System components and models that can be handled.

a. Plant Models

Thermal plants (Once through, Drum),
Nuclear plants (BWR, PWR),
Hydro plants
  1.simplified turbine and conduit model (1-Ts/1+1/2Ts)
  2.pump-turbine complete characteristics and elastic conduit model
Gas turbines (simple model with governor model)

b. Speed governor models

Thermal Plants
  1.Simple models (Speed governor + Control valves),
  2.Detail models (MHC(Mechanical Hydraulic Control),
    EHC(Electro-Hydroulic Control),including intercept valves and over speed protection)
Nuclear Plants
  Detail models (MHC, EHG, including intercept valves, over speed protection, and bypass valves)
Hydro Plants
Gas Turbines

c. Generator and Motor models

Synchronous machine : simplified Park's model (i.e. $p\Psi d=p\Psi q=0$) saturation
Induction machine : rotor dynamics (armature transient neglected)

d. Excitation System Models

AVR, PSS
OEL, UEL, AQR, APFR or other functions can be used

e. Transmission System Models

Transmission lines : equivalent
  positive, negative, zero sequence representation
  algebraic equation (dynamics are neglected)
Transformers : jX, tap

f. Load models

Static load model : function of voltage and frequency
Dynamic load model :
  Induction machine-torque is a function of rotor speed
  Linearized dynamic load model
  Load trip characteristics by voltage drop
Static Var compensator

g. Relay models

Frequency relay : under, over, derivative under-frequency relay
Function : load shedding, unit trip, branch open
Step-out relay :

3-7. Representation of generator dynamics

b. Simplified Park's model / Swing equation for individual units

3-8. Method of load flow computation

a. AC model

At each time step

3-9. Disturbance of that can be handled

a. Load change at buses
b. Loss of load feeders
c. Loss of generating plants
d. Change of generating plants
e. Loss of transmission lines (this includes Loss of switching station and substation)
h. Scenario comprising the combination of such disturbances
i. Others
  Setting point change such as in AVR or Governor
  Tap change of transformers
  Faults including unsymmetrical condition

3-10. Analytical techniques for simulation

a. Simulation time range

A few seconds to a few minutes.

b. Time steps

Typically 0.01 second.

c. Numerical integration technique

4-th Runge-Kutta (fixed time step).

d. Model change

None

e. Frequency / voltage deviation

Typically, for sustained derivation	1Hz,	-20% to +10% voltage
for transient change	3Hz,	-100% to +30% voltage

3-11. How to handle or actions of operator

Sequence setting (input data setting)

3-12. Information from the program/simulator

a.,b.,c. and d. in the explanation of "QUESTIONNAIRE ON LONG-TERM DYNAMICS (L-T-D) IN POWER SYSTEMS".

3-13. Initialization of program/simulator

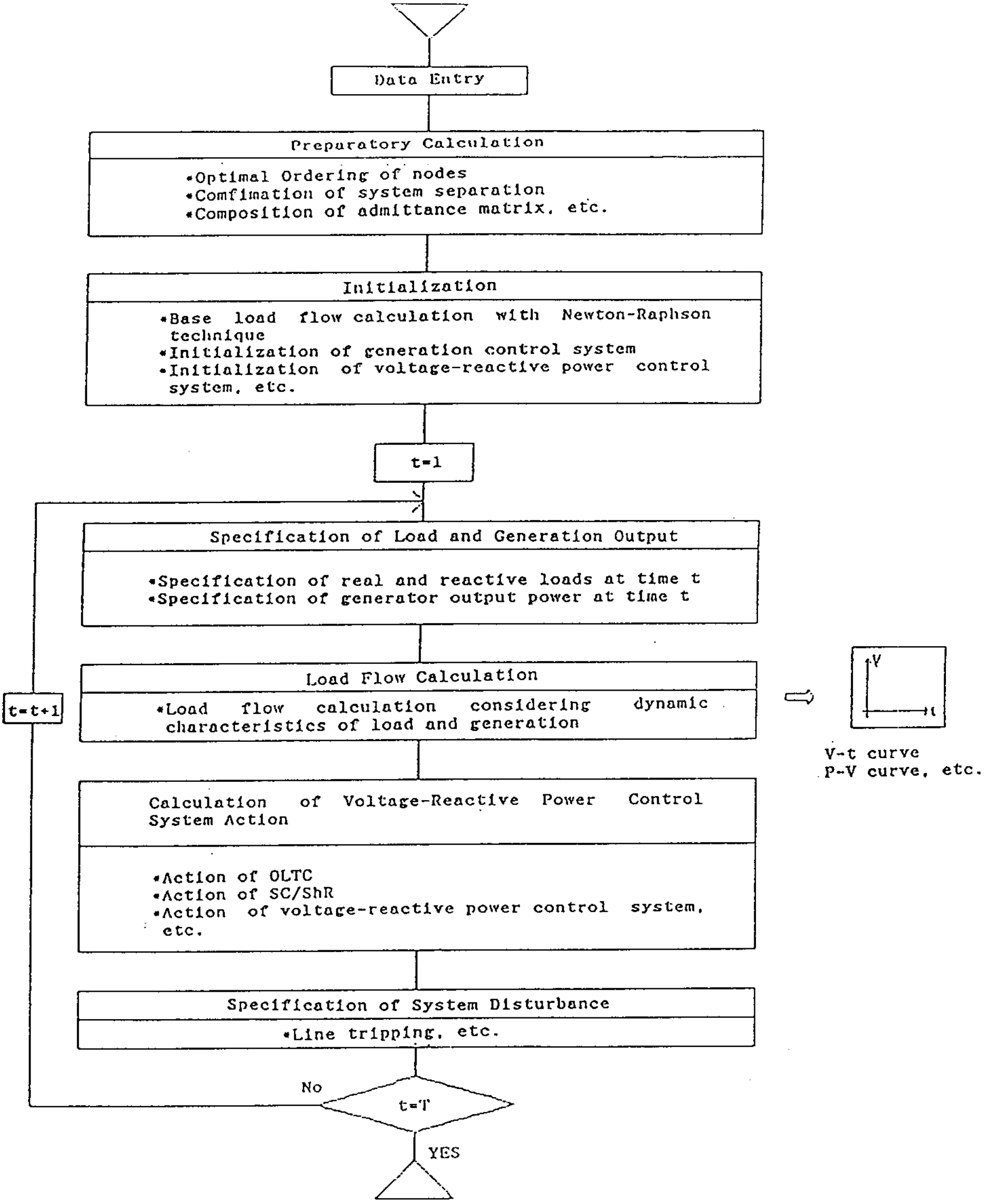
The initial condition of plants, controller and so on are automatically determined and set from initial power flow calculation result and their constants.

14. Interface of program/simulator

Special interface are not used for the program except usually equipped in a large computer system.

3-15. List of the reference(s)

To be published,
'Aggregated Large-scale-software for Power-System Stability', CRIEPI Report.



Analysis Method for Power System Voltage Dynamics

Program(5) AGCSTM2

U.S.A C-2 (ECC I.) (Format C)

Current Status and Perspective of Analytical Tools

3-1. Name of the project

AGCSTM2

3-2. Name of organization(s)

ECC, Inc.

3-3. Stage and time of development

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a. Stage of the development

[( )Planning, ( )Prototyping, ( )Testing, (X)Practical]

b. Date of commencement

1987

c. Date of completion

Version 1 1989

d. Target year of completion

Version 2 1991

e. Other

3-4. Motivation and objective of the L-T-D analytic program/simulator development

---

Synthesis and evaluation of AGC and of Var control.

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

See attached.

b. Structure and general flow of the program/simulator

See attached.

c. Environment of the program/simulator

VAX/VMS
IBM PC and compatibles.

d. Scale of the test system that can be handled

Direct function of available memory

FEATURES

CAPABILITIES

System models are built, units may be added or deleted, and their parameters may be modified, interactively. Default values are provided for all unit types, so only minimal information need be entered to specify a new unit.

A wide variety of AGC systems, including and advanced dynamic dispatch, may be constructed by the user from a menu of alternative AGC elements. Incremental cost curves may be specified interactively.

The execution interval may be specified interactively for any period of time for which load data exists.

A scenario of events may be scheduled to take place during the simulation (this is a means of handling unit commitment and tie-line schedules, etc. that the load predictor and dynamic dispatch will take into account).

System disturbances may be imposed at user defined times (this is a means of specifying disturbances that will not be foreseen by the load predictor).

The user may choose variables to observe as they evolve in time; this choice may be changed at any time. Also a user selected list if variables may be stored into an output file for system performance monitoring during simulation interrupts or after simulation completion.

The program execution may be interrupted at preselected or arbitrary times, at which point:

- any of the preselected variables may be viewed as they have evolved in time up to the interrupt;
- the load may be changed by an increment to be added to or subtracted from the actual load, from that time on;
- any of the preselected variables may be "dumped" to a file for a later processing;
- a new choice of variables to be monitored may be made;
- the program may be instructed to proceed.

Execution speed depends upon the size of the system that is simulated and the type of AGC function that is configured, as well as upon the hardware. For a system of twenty generating units, with dynamic dispatch, typical execution times are three to five times real time on either a VAX II/750 or an IBM AT 386.

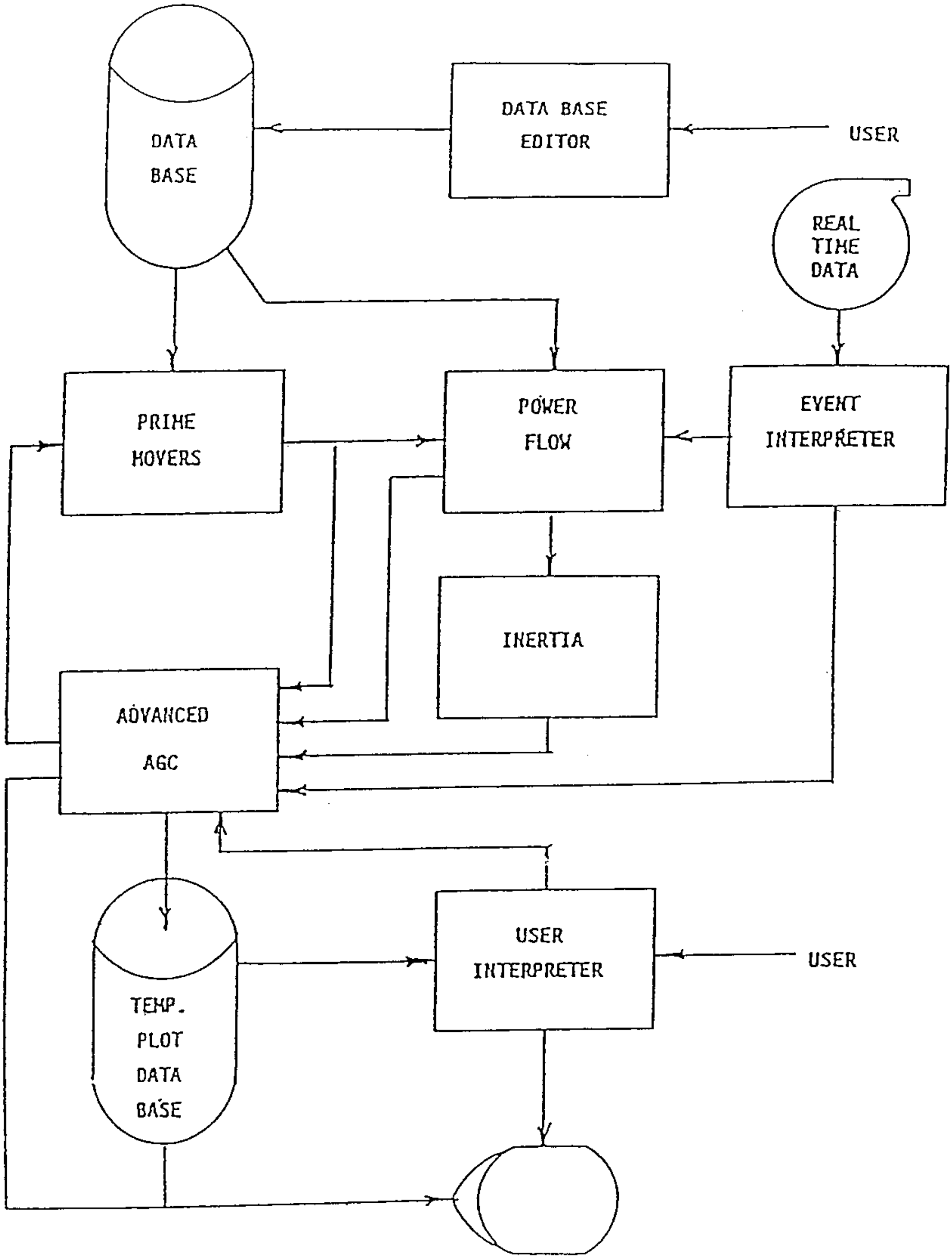


FIGURE 2. ADVANCED AGC SIMULATOR

3-6. System components and models that can be handled

Version 1 - See attached.

Version 2 - additional:

- voltage/frequency dependent loads
- reactive capability
- TGUL transformers
- frequency and voltage dependent unit auxiliaries
- induction motors
- static VAr controllers
- underfrequency, under voltage relays
- overhead and underground cable thermal models
- transformer thermal models
- contigency analysis

etc.

3-7.Representation of generator dynamics

None - Mechanical power in generator output.

3-8. Method of load flow computation

Fast-decoupled.

3-9. Disturbance of that can be handled

Loss of model
Sudden load change
Loss of line(s)
Frequency and voltage excursions

3-10. Analytical techniques for simulation

a. Simulation time range

Up to 24 hours.

b. Time steps

1 seconds, except 0.5 sec. for boiler dynamics.

c. Numerical integration technique

Trapezoidal

d. Model change

Data editor and/or menu

e. Frequency / voltage deviation

3-11. How to handle or actions of operator

Programmed events : scheduled unit start-up, shut-down, changes to limits, etc.

Contingencies : loss of unit, loss of line.

3-12. Information from the program/simulator

Time trajectory of selected variables (flows, voltages, powers).

3-13. Initialization of program/simulator

Automatic. Extend data is total system load history, solved load flow, type of dispatch algorithm, duration of run.

3-14. Interface of program/simulator

Interactive.

3-15. List of the reference(s)

An Advanced Dispatch Simulator with Dispatch Algorithm;
R.J.Kafka, L.H.Fink, N.J.Balu; H.G.Crim, Jr.;
IEEE Computer Applied in Power, v.2 n.4, October 1989, pp 30-35.

Application of the Developed Program/Simulator to Test Systems

4-1. Outline of the teat system

1 Company 1: 16 plants (no network)
2 Company 2: 9 plants (no network)
3 Company 3: 15 plants (no network)
4 Company 4: plants (131 bus network) (IEEE Scenario D system)

4-2. Condition and scenario in the simulation

1 through 3: 24 hour load following, units on/off-line, local ACE feedback or external control.
4: 1 hour, successive loss of four units at ten-minute intervals; examine bus voltages, generator P and Q.

4-3. Simulation results

In addition to time-histories of variables:
Production cost, inadvertent, unit reversals, total unit movement, unit movement/reversal, etc.

4-4. Consideration on the application result

4-5. Validation methods

Cases 1 thru 3 validated against recorded plant input/outputs.

Future Development/Improvement

5-1.Problems to be solved on the application of the program/simulator

AGC performance evaluation.
Comparison of different dispatch algorithms in terms of performance and economics.
Evaluation of voltage control and system voltage response to contingencies

5-2. Points to be improved in the future

More detailed turbine models, improved data base and user interface.

5-3. Future development plans or new projects

Expand set if voltage control devices; add thermal models of lines and transformers; add graphics.

Name of respondent(s), organization(s), country

Lester H.Fink
ECC, Inc.
U.S.A.

Program(6) Dynamic Model of the Power System Behaviors

(Format C)

Current Status and Perspective of Analytical Tools

3-1. Name of the project

Dynamic Model of the Power Systems Behaviors

3-2. Name of organization(s)

Yugoslavia Sarajevo Power System Institute

3-3. Stage and time of development

---

a. Stage of the development

[( )Planning, ( )Prototyping, ( )Testing, (X)Practical]

b. Date of commencement

1968

c. Date of completion

1978

d. Target year of completion

e. Other

3-4. Motivation and objective of the L-T-D analytic program/simulator development

---

Electrical Oscillation, dynamic stability problem, system protective relay testing, load shedding, dispatcher training and education.

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

b. Structure and general flow of the program/simulator

c. Environment of the program/simulator

VAX computer

d. Scale of the test system that can be handled

80 buses, 12 generators, 20 load models

3-6. System components and models that can be handled.

Analog type generator model, 15 types of load model any type of system disturbance.

3-7. Representation of generator dynamics

Analog model

3-8. Method of load flow computation

9. Disturbance of that can be handled

any type of disturbance

10. Analytical techniques for simulation

a. Simulation time range

From 1 msec to a few minutes

b. Time steps

any time

c. Numerical integration technique

d. Model change

e. Frequency / voltage deviation

3-11. How to handle or actions of operator

3-12. Information from the program/simulator

3-13. Initialization of program/simulator

3-14. Interface of program/simulator

3-15. List of the reference(s)

Application of the Developed Program/Simulator to Test Systems

4-1. Outline of the test system

4-2. Condition and scenario in the simulation

4-3. Simulation results

4-4. Consideration on the application result

4-5. Validation methods

Future Development/Improvement

5-1.Problems to be solved on the application of the program/simulator

5-2. Points to be improved in the future

5-3. Future development plans or new projects

Name of respondent(s), organization(s), country

Power System Institute, Sarajevo, Yugoslavia

cigré

Appendix <4>

Simulator for L-T-D in Operation

Simulator(1)	Advanced Power System Analyzer: APSA (KEPCO)
Simulator(2)	Advanced Power System Simulator: APOSS (HEPCO/TOSHIBA)
Simulator(3)	Transient Network Simulator: TNS (Fuji Elec. Co.)
Simulator(4)	Real-Time Prototype of Power System Simulator: PPSS (ENEL)

Simulator(1) Advanced Power System Analyzer: APSA

(Format C)

Current Status and Perspective of Analytical Tools

3-1. Name of the project

APSA, Advanced Power System Analyzer

3-2. Name of organization(s)

Kansai Electric Power Co.LTD

3-3. Stage and time of development

a. Stage of the development

[( )Planning, ( )Prototyping, ( )Testing, (X)Practical]

b. Date of commencement

None

c. Date of completion

April in 1989

d. Target year of completion

-----

e. Other

3-4. Motivation and objective of the L-T-D analytic program/simulator development

Digital simulation, including EMTP, have formerly been used in many cases for analyzing the phenomena arising in power systems. Digital simulation is capable of high-precision analyses in the respective regions of phenomena as different algorithms are applied in accordance with the domain so of phenomena to be analyzed. On the other hand, it has the drawback of grasping continuous phenomena arising in actual system only in fragmentary form.

In the study of important projects of the world, therefore, analogue simulations capable of continuously analyzing the phenomena from the fault occurrence to the steady state region are used in combination. By this means the accuracy of analyses is improved while at the same time making use of the simulations for inferring possible occurrence of unpredictable phenomena.

Analogue simulators, however, consist mostly of small-scale simulators composed of several generator models, and application of their functions is limited to analyses of systems are to be analyzed, it would not be possible to advance further than qualitative studies with these simulators.

On the other hand, power systems of the world are advancing in the direction of larger scales and greater complexities, which require higher reliability.

Under such trends found in power systems, study of numerous technical problems, such as determination of proper power systems configuration, development of control techniques for improving the system reliability and introduction of new equipment applying new techniques, has become necessary.

The completed simulator APSA is capable of coping with various phenomena ranging from transient phenomena of several milli second to demand-supply balancing phenomena lasting for nearly an hour.

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

The simulator has features cited below.

- It is a large-scale system composed of a total of some 500 units, including 30 generators, 304 transmission lines, 20 units of load and some DC transmission SVC.
- Unique models, such as generator models capable of simulating synchronous machines, induction machines and simulating voltage characteristics having time-dependent characteristics in addition to frequency characteristics, have been adopted.
- High-performance man-machine interfaces, such as connection data input by system diagram image from work stations and control system data input by block diagram, have been adopted.
- Adopting automatic selection of the optimal unit and the automatic wiring system for composing the main circuit, labor saving in connecting tasks has been promoted.

b. Structure and general flow of the program/simulator

As shown in attached Figure 1.

c. Environment of the program/simulator

As shown on attached Figure 2.

d. Scale of the test system that can be handled

As shown on attached Figure 2.

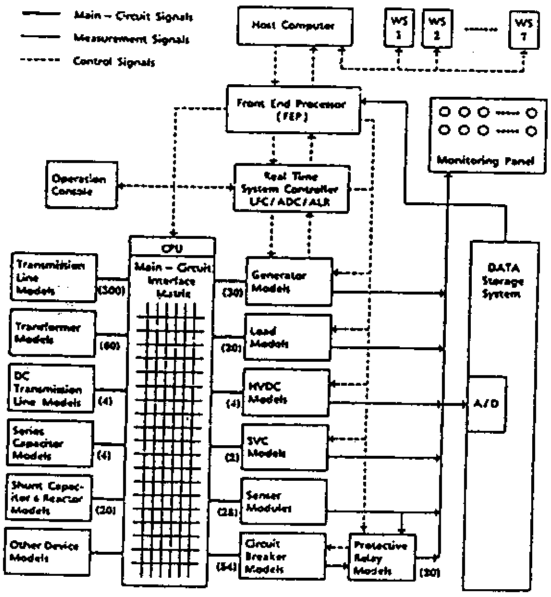


Fig. 1 Construction of APSA

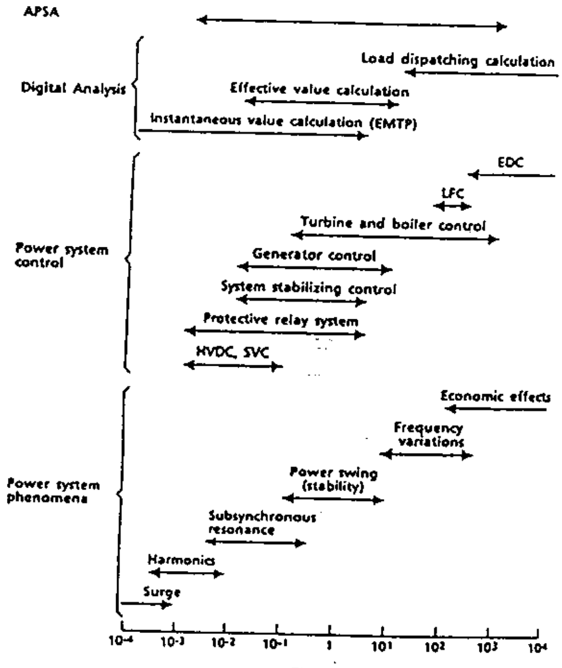


Fig. 2 Power System Phenomena and its time period

3-6. System components and models that can be handled.

a. Not considered.

b. Models of hydro electric, thermal electric, nuclear and gas turbine power generators and FV are under consideration.

c. Models of the synchronous machines, induction machines and speed governors are under consideration.

d. With respect to AVR, DC type and thyristor type models are divided into the self-excitation scheme are prepared. Furthermore, PSS, APFR and AQR models can be handled.

e. Transmission line models are represented by reactors with iron core. The model is the T shaped L.C.R. type, and in accordance with the purposes of use, 3 kinds, including detailed model of transposed 2-circuit transmission line, equivalent model of 1-circuit transmission line and unbalanced 2-circuit transmission line model capable of indication non-transposition, are made available.
The transformer model is composed of a combination of the ideal transformer mounted with the saturation characteristic variable tap, the voltage tap for adjusting the transformation ratio and the externally variable reactance for leakage reactance Four types, including the 2-wining type for generator use, the autotransformer for general use, the 3-winding type and the single-phase type, are made available.
As phase modifying equipment, SC, ShR, and SVC are made available.
As models of the static characteristics of the load, indications of P,Q are made by power if the voltage and the linear equation of frequency deviation. As dynamic characteristics models, time lag and advance of first order were taken into consideration of load admittance variations.
The relay model contains 15 kinds of factors, including frequency decline and voltage drop. The central control models for the load frequency and generator output has the AFC, ELD and ALR functions. Also as the system stabilizing control, BSS and the generator output limiter functions are considered.

3-7. Representation of generator dynamics

The detailed Park's model is used for each generator unit. As the computational methods of this model, two systems, the digital and analogue, have been adopted.

3-8. Method of load flow computation

3-9. Disturbance of that can be handled

With respect to the load, the load fluctuation for LFC and the load limiter function by external signal(start-up relay SSC) are available. with regard to the feeder load, transmission lines and the switchyard, simulation of the loss of load and load shedding is possible by means of the operation of the circuit breaker of the simulator as in an actual system.

3-10. Analytical techniques for simulation

a. Simulation time range

From several msec to several tems of minutes.

b. Time steps

Real time.

c. Numerical integration technique

-----

d. Model change

Connection and disconnection of units during simulation are possible, bur change of generator models is not possible.

e. Frequency / voltage deviation

3-11. How to handle or actions of operator

Generator output change and open/close of circuit breakers by manual operations are possible as needs arise.

3-12. Information from the program/simulator

Information obtained from the simulator are as follows ;

* Generator - Output power, voltage, phase current frequency, field voltage, field current, damper winding current, inner phase angle, inner induction voltage, turbine output, main value position, ICV position, OPC signal, tripping time of protective relay.
* Load - Capacity, phase voltage, current, tripping time of frequency decline relay.
* Circuit breaker - Power flow, voltage, current, state of circuit breaker.
* Others - Loss shedding command, generator shedding command, total demand, AFC margins, ELD requirement, up and down signal of transformer LTC.

3-13. Initialization of program/simulator

The simulator automatically starts up so that the generator outputs and loads will assume the desired value, thus providing the initial power flow states. The system of having the infinite bus model incorporated at the starting up time is follows in order to adjust the imbalance of generator outputs during starting up.

3-14. Interface of program/simulator

In the system simulator operations is supported with a computer and the operator execute most of inputting and outputting operations from the work station connected with the computer.

3-15. List of the reference(s)

H. DOI, et al, : " Advanced Power System Analogue Simulator,"
IEEE '90 WH242-8 PWRS PSE.

Application of the Developed Program/Simulator to Test Systems

4-1. Outline of the test system

None as of now.

4-2. Condition and scenario in the simulation

Development of the generator plant model and new type plant models like fuel cells.

Reflection of the result of the simulator operation on the improvement of various functions.

4-3. Simulation results

None as of now.

4-4. Consideration on the application result

Kansai Electrical Power Co.LTD

4-5. Validation methods

Future Development/Improvement

5-1. Problems to be solved on the application of the program/simulator

5-2. Points to be improved in the future

5-3. Future development plans or new projects

Name of respondent(s), organization(s), country

Simulator(2) Advanced Power System Simulator

(Format C)

Current Status and Perspective of Analytical Tools

3-1. Name of the project

Advanced Power System Simulator (APOSS)

3-2. Name of organization(s)

(1) Hokuriku Electric Power Co.
(2) Toshiba Corporation

3-3. Stage and time of development

a. Stage of the development

[( )Planning, ( )Prototyping, (X)Testing, (X)Practical]

b. Data of commencement

January, 1988

c. Data of completion

June,1990

d. Target year of completion

e. Other

3-4. Motivation and objective of the L-T-D analytic program/simulator development

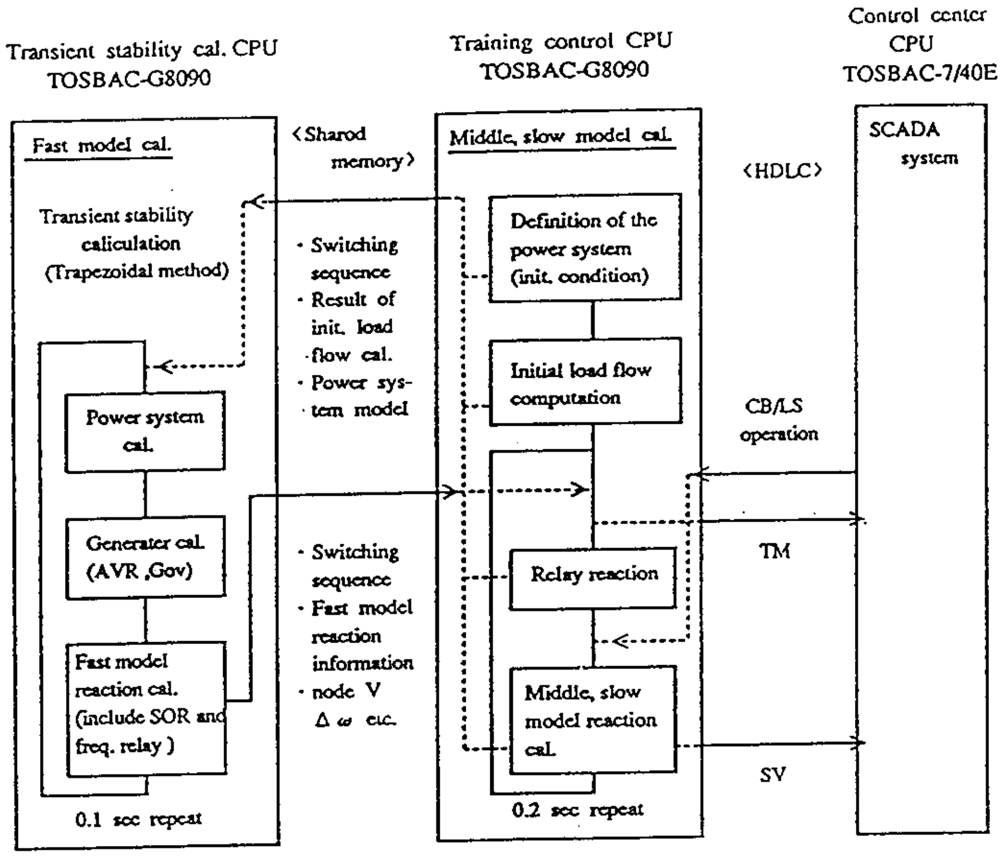
Training of power system operators of regional control center.*
* regional control center
Control and dispatching of observed stations.

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

(1) Real-time transient stability calculation
(2) Large scale,broad and detailed power system simulation
(3) Same training environment as actual control center

b. Structure and general flow of the program/simulator



c. Environment of the program/simulator

(1) Computer used for the development.
    TOSBAC-G8090 x2 , TOSBAC-7/40E
(2) Computer used for practical operation.
    TOSBAC-G8090 x2 , TOSBAC-7/40E
(3) The operating system (OS).
    OS/V (G8090)
    TREX (7/40E)
(4) The program language.
    FORTRAN, C, PL/G
(5) Necessary memory capacity.
    Main memory : 64MB x2 (G8090)
    1MB (7/40E)
    Shared memory : 8MB
    HDD : 799MB x2 (G8090)
    157MB,268MB (7/40E)

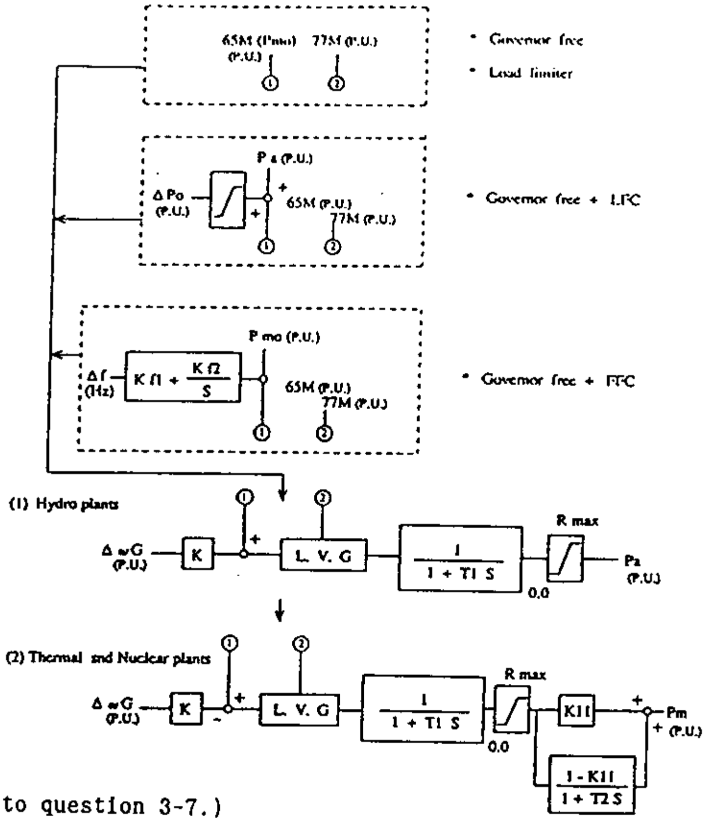
d. Scale of the test system that can be handled

(1) Number of buses (nodes) : 450 (max)
(2) Number of generators : 130 (max)
(3) Number of load points : 320 (max)
(4) Number of AGC areas : 2 (LFC 1,FFC 1)
(5) Number of voltage and reactive power controllers : 184 (max)
(6) Number of protective relays : 1881 (max)

3-6. System components and models that can be handled.

a. Plant models

None



b. Speed governor models

(1) Hydro plants
  * Governor free
  * Governor free + LFC
  * Governor free + FFC
  * Load limiter
(2) Thermal and Nuclear plants
  * Governor free
  * Governor free + LFC
  * Governor free + FFC
  * Load limiter

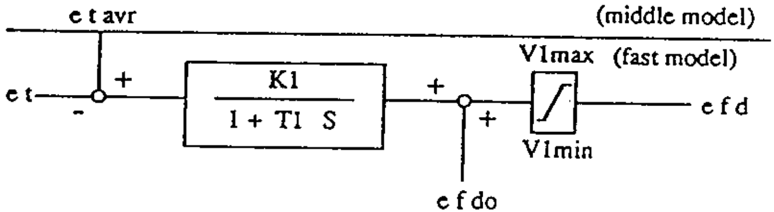
c. Generator models

(1) Synchronous generators
  * Transient model (please refer to question 3-7.)
  * Xd' model (please refer to question 3-7.)
(2) Induction generators

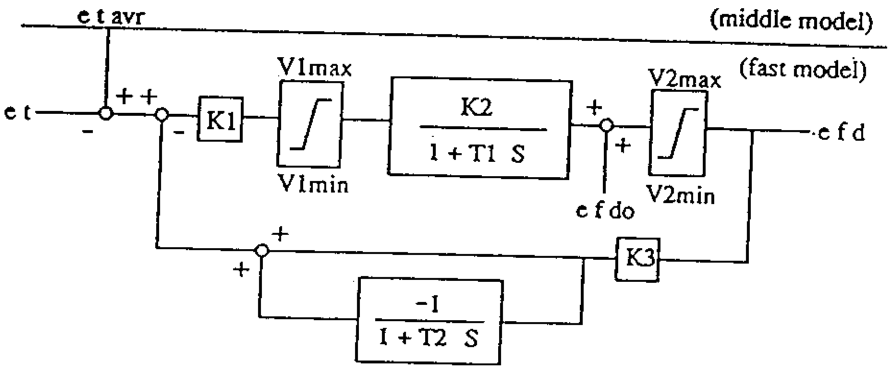
None

d. Excitation system models

(1) AVR
  * Time-lag of first order model



  * Time-lag of first order and unti-hunting feed-back circuit model



(2) PSS
We substitute Generator damping constant for PSS.

e. Transmission system models

(1) Transmission line
   type, Positive sequence, detailed (1 line/cct.)
(2) Transformers
 Detailed with tap changer(1 unit /bank)
 Secondary and tertiary winding transformer model
(3) Under excitation controller, Over excitation controller, Automatic reactive power regulator
  * AQR/APFR/AVR models(setting value changed by 4sec)
(4) On-load tap changer,shunt capacitor,shunt reactor
  * LRT (2 tap up/down /30sec)
  * SC/SHR (on/off /1min)

f. Load models

(1) Static load characteristics
  * Voltage/frequency characteristics
    $P_L(t, V, \Delta f) = P_0(t) V^2 (1 + K_L \Delta f)$
  * Load sustained and fringe parameter considered
(2) Dynamic load characteristics
  * Loss/recovery characteristics of load by both voltage drop and power stoppage

g. Relay models

(1) Frequency relay
  * Under-frequency (Load,Generator,line CB trip)
  * Over-frequency (Generator,line CB trip)
(2) Voltage relay
  * Under-voltage (Load,SC,SHR,line voltage SV etc.)
  * Over-voltage (SC)
(3) Protection relay
  * Line/Transformer protection (Main/Back) relay
  * Bus protection relay
  * Bus device relay
    They act by logical decision.
(4) Reclose relay
  * Fast/middle/slow reclose relay
(5) Over-load relay
  * Transformer protection relay/alarm
  * Transmission line over-load relay
(6) SOR
(7) Over-current relay
  * Generator trip

h. Dispatch center/system stabilizing control model

(1) AGC
  * LFC
(2) Voltage and reactive power control
 (* VQC)
(3) System Stabilizing controller
  * LBC(Load ballance control=SSC)
(4) Others
  * OL
  * PSC(Power Swing control)
 They act on the same program as an actual dispatch center system.

3-7. Representation of generator dynamics

Simplified Park's model/ Swing equation for individual units.

- Transient model

$$\left[\begin{array}{l} d\delta/dt = \omega_0 \Delta\omega \\ d\omega/dt = 1/M(Pm - Pe - D\Delta\omega) \\ dEq'/dt = 1/Tdo'(Efd - Eid) \\ dEd'/dt = 1/Tqo'(-Eiq) \end{array}\right.$$

[Gen. const. Xd,Xq,Xd'(=Xq'),Xl]
Used in large generators

- Xd' model

$$\left[\begin{array}{l} d\delta/dt = \omega_0 \Delta\omega \\ d\omega/dt = 1/M(Pm - Pe - D\Delta\omega) \\ E = X_0 \cdot Efd(\text{AVR output}) \end{array}\right.$$

[Gen. const. Xd']
Used in small generator

3-8. Method of load flow computation

Detailed power flow computation (AC model)
This flow computation run only one time to determine initial condition on the power system.

3-9. Disturbance of that can be handled

a. Load change at buses
b. Loss of load feeders
c. Loss of generating plants
d. Up/down of generator outputs
e. Loss of transmission line
f. Loss of switching station
g. Loss of substation
h. 3 phase short accident
i. accident sequence comprizing the combination of such disturbances
j. Setting relay action lock and CB action Lock

3-10. Analytical techniques for simulation

a. Simulation time range

Real time (0 to 3 hours)

b. Time steps

100 msec (transient stability computation)

c. Numerical integration technique

Trapezoidal method

d. Model change

AVR/AQR mode change (generators)

e. Frequency / voltage deviation
Frequency : no limits, if transient stability computation can practice.
Voltage : no limits, if transient stability computation can practice.

3-11. How to handle or actions of operator

The action of the operator are carried out on CRT by picking points and pushing the button.

3-12. Information from the program/simulator

a. Dynamic responses of power flow, voltage phase angle, etc.
b. Relay action
c. Action of controllers
d. Operator action

3-13. Initialization of program/simulator

a. SV setting (CB,LS,43SW,SV initial condition)
b. Load setting (load pattern and each load initial value (P,Pf))
c. Generator output setting (each generator output value (P,Q,V,Pf) and control mode setting)
d. Voltage and reactive power setting (LRT tap, SC, SHR)
e. Dispatch center program mode setting (LFC,VQC,LBC,PSC,OL mode setting)
f. Accident point and feature setting (line, bus, short, ground, time)
g. Relay action check and setting (relay lock, etc.)

3-14. Interface of program/simulator

CRT, key board, stylus pen, operator button

3-15. List of the reference(s)

TOSIBA REVIEW Vol.45, No.1, 1990, pp.47-50, PUBLISHED by TOSIBA CORPORATION

Application of the Developed Program/Simulator to Test Systems

4-1. Outline of the test system

4-2. Condition and scenario in the simulation

4-3. Simulation results

4-4. Consideration on the application result

4-5. Validation methods

Future Development/Improvement

5-1.Problems to be solved on the application of the program/simulator

None

5-2. Points to be improved in the future

5-3. Future development plans or new projects

Name of respondent(s), organization(s), country

Hikoni Yanagida, Hokuriku Electric Power Company, Electric Engineering Dept., Power System Operation Section, Japan.

Simulator(3) Transient Network Simulator:TNS

Japan C-10 (Fuji E.C.) (Format C)

Current Status and Perspective of Analytical Tools

3-1. Name of the project

Transient Network Simulator (TNS)

3-2. Name of organization(s)

Fuji Electric Co., LTD.

3-3. Stage and time of development

a. Stage of the development

[( )Planning, ( )Prototyping, ( )Testing, (X)Practical]

b. Date of commencement

1980

c. Date of completion

1990-3 (1st Stage)

d. Target year of completion

1995 (2nd Stage)

e. Other

3-4. Motivation and objective of the L-T-D analytic program/simulator development

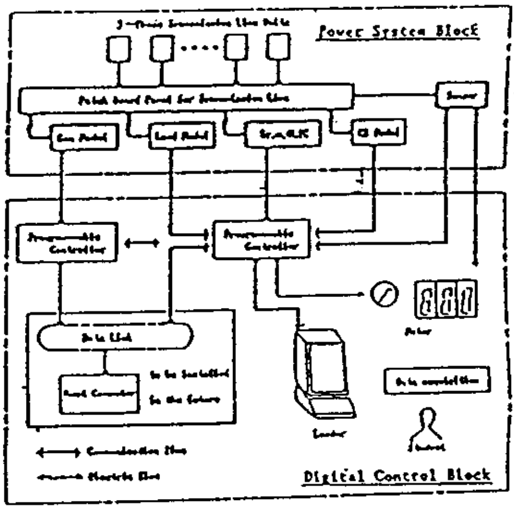
1) Development of prevention system for cascaded faults
2) Development and verification of system stabilization
3) Research for load characteristics and voltage instability
4) Development and verification of Artificial Intelligent System
5) Education
6) Development of "In-Line Simulation System"

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

1) System rating : Voltage 5-10 V. Current 5-100 mA.
2) Equipment model : Generator, Load, SVC, Induction Motor, Voltage and Var controller
3) Total performance test of real control system
4) Real time

b. Structure and general flow of the program/simulator



c. Environment of the program/simulator

Room scale : 11m × 12m

d. Scale of the test system that can be handled

Generator	:	6 sets (Changeable for Induction Motor, Synchronous Motor)
Controller	:	4 sets (Digital), 2 sets (Analog)
Load model	:	7 sets
Line model	:	About 2500 Km
Others	:	SVC(2 sets), VQC(3 sets), Load of Rectifier(3 sets)

3-6. System components and models that can be handled.

a. Plant Model (See Fig.1) Thermal Plant: Boiler Dynamics (Steam temperature, Flow) is neglected. If necessary, select the simplified block diagram with only a gain and time constant.
   Hydro Plant: Penstock

b. Speed Governor: Thermal, Hydraulic, Gas Turbine (including Turbine Servo Mechanism) (See Fig.1)

c. Generator Model: Detailed Park Model

d. Excitation: AVR PSS (including excitor)

e. Line model: Simplified positive three phase transmission, constructed by single phase L-type elements with resistance, reactance and capacitance.

f. Load model: Composed of hybrid analog and digital devises. Load characteristics expressed by constant power, current, impedance with voltage and frequency dynamics.

g. Relay model: Digital type universal relay system (in future).

h. Voltage and reactive power control (Installed real system)

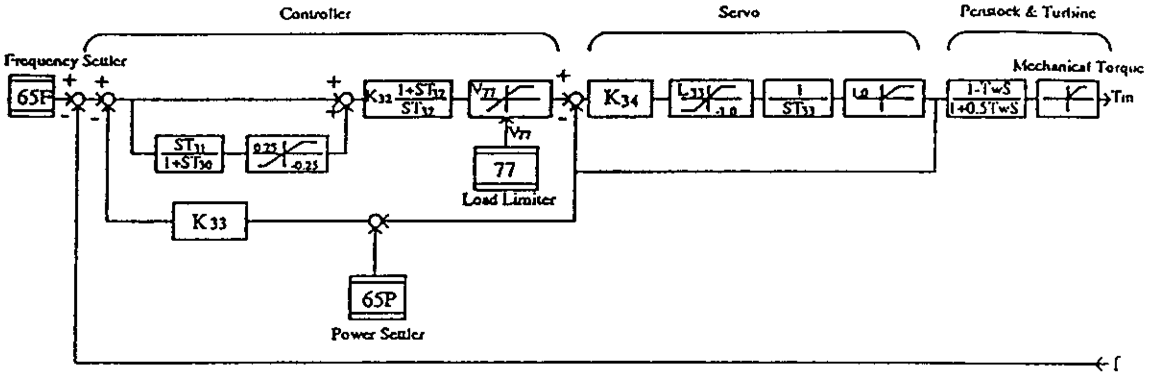


Fig.1(a) Governor / Turbine Block Diagram for Hydro Power Plant

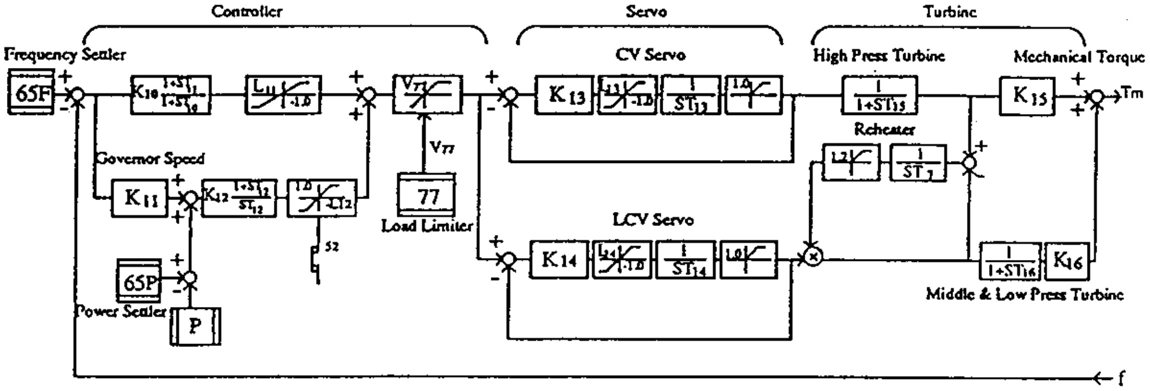


Fig.1(b) Governor / Turbine Block Diagram for Thermal Power Plant

▭ Thruugh this type of Hock, reference value are Fed into the Control Blick by the uper during operator of TNS

3-7. Representation of generator dynamics

a. detailed Park's model (three phase)

3-8. Method of load flow computation

Calculated on analog system (circuits)

3-9. Disturbance of that can be handled

a-h are available

3-10. Analytical techniques for simulation

a. Simulation time range

no limitation

b. Time steps

Controller's sampling time Is 10 msec(AVR) and 50 msec(GOV)

c. Numerical integration technique

d. Model change during simulation,

Constants of controller : yes
Controller block diagram : no

e. Frequency / voltage deviation

Frequency : 20 deviation
Voltage : up to 300

3-11. How to handle or actions of operator

All setting references can be changeable by manual operation.

3-12. Information from the simulator

Data acquisition system (sensor, sampler, memory) is used.

3-13. Initialization of simulator

Using Infinitive power sources, power flow can be set according to power flow data by digital simulation.

3-14. Interface of simulator

3-15. List of the reference(s)

Y.Tamura, E.Dan, I.Horie, Y.Nakanishi, S.Yokokawa,
"Development o Power System Simulator for research and education",
IEEE PES Winter Meeting, 89 SM 653-7 PWRS.

Application of the Developed Program/Simulator to Test Systems

4-1. Outline of the test system

4-2. Condition and scenario in the simulation

4-3. Simulation results

4-4. Consideration on the application result

4-5. Validation methods

Future Development/Improvement

5-1.Problems to be solved on the application of the program/simulator

1) Data acquisition system (including documentation)
2) Development of universal model using micro CPU.
3) Improvement of sensor system.

5-2. Points to be improved in the future

1) Voltage Instability and new system prevent it.
2) Development for improvement power system stability.
3) Development for new relaying system.

5-3. Future development plans or new projects

1) Development of Long-term dynamics program simulation.
2) Development of "Inline simulation system."

Name of respondent(s), organization(s), country

Fuji Electric Co., LTD.
Power System Control Development Dept.
S.Yokokawa (Y.Nakanishi)

Italy C-2 (ENEL) (Format C)

Current Status and Perspective of Analytical Tools

3-1. Name of the project

Real-time prototype of power system simulator: PPSS

3-2. Name of organization(s)

ENEL

3-3. Stage and time of development

a. Stage of the development

[( )Planning, (X)Prototyping, ( )Testing, (X)Practical]

b. Date of commencement

1.1.1984

c. Date of completion

31.12.1985

d. Target year of completion

e. Other

3-4. Motivation and objective of the L-T-D analytic program/simulator development

The aim of the enterprise was that of checking the performance of the simulator with respect to different goals: i) operator training, ii) a tool for them control center, iii) a means to improve engineering understanding of power system phenomena, and at the same time, to ascertain the feasibility of the simulator with regard to real time performance, to power system size and to software/hardware costs.

The prototype makes use of a well-known modelling approach developed in off-line digital program STRALE.

In particular,the prototype is able to reproduce the static and dynamic behavior of a power system in the field of low frequencies variations due to the demand, to the schedule of production, to the regulation of supply systems and prime movers (both thermal and hydro) and to the load-frequency control. Furthermore, all the events or restoration, can be simulated.

The prototype has been successively installed by ENEL's National Control Center with the aim of extracting from the user's experience more detailed indications of a possible finalized simulator.

3-5. Outline of the L-T-D program/simulator

a. Features of the L-T-D program/simulator

The maximum size of a power system to be simulated is expressed in about 70 nodes and 15 power stations: these limits are due to the need to have the computing time less than the real time, the solution of the algebraic part (see Fig.4) being made every 1 sec of real time and the integration step(equal to 0.2 sec) of the dynamic part being imposed by numerical reasons.

During the run of the simulator it is possible to ask every display, the production of which on the CRT requires up to 20 sec in the worst case (the most complex scheme with the current values of the variables).

The foreground variables are refreshed on display every 10 sec.

b. Structure and general flow of the program/simulator

PPSS consists of a hardware-software structure that simulates in real-time the mathematical model of the electric power system as well as the services most suitable for making it accessible on line.

Man-machine interaction is provided for by a console, the purpose of which is both to supply all the information concerning the simulations by means of the outputs typical of modern supervisory systems (prints, video pages, etc.), and to provide the most suitable aids to instruction. In particular, the following was considered;

- electorical scheme of the whole electoric power system simulated, containing a synthesis of information on the instantaneous operating conditions;
- electrical schemes of parts (or of areas) of the simulated system containing detailed information;
- temporal behaviour of the main network quantities (voltage, frequencies, active and reactive power flows, etc.);
- bar-chart of voltages profile;
- bar-chart of active and reactive productions of the various power stations and overall spinning reserve;
- block diagrams (as in Fig.s 2,3 and 4 of STRALE);
- diagrams showing unit variables (valve opening, steam flow, excitation current, capability curves, etc.).

Referring to the software structure, it may be divided into two categories: off-line programs and real time programs.

The first category includes

- the definition of the network structure and of the initial steady-state conditions carried out by means of ENEL's usual off-line programs;
- the initialization of the man-machine dialogue by means of the schematic data of the various displays.

The structure relating to the real-time simulation is similar to that previously realized by ENEL in the field of Thermal Power Plant Simulators.

As regards service and man-machine-interaction activities, these are based on a tabular structure , which defines all the relevant and pre-established sets for the functions to be performed on those variables.

The corresponding table contains a mnemonic name, the position in the data base, and the measuring unit.

For each of the functions that can be called up and performed on-line, a group of tables containing the type of function, the variables, and the parameters, has been preset.

c. Environment of the program/simulator

The hardware configuration consists of:
- a GOULD 32/27 cpu
- a 2 Mb central memory
- a 150 Mb disk unit
- a magnetic tape unit
- a printer
- a black-and-white CRT
- two coloured graphic CRT'S

d. Scale of the test system that can be handled

A part of the ENEL HV Network

3-6. System components and models that can be handled.

In the PPSS only some phenomena related to LTD are represented:
- primary frequency control,
- behavior of the supply systems and of the prime movers and their regulations,
- load-frequency control, or secondary frequency and exchanged powers control,
- operation of the over and under excitation limiting circuits of the units,
- automatic load-shedding,

For other information see point 3-6 of STRALE.

3-7. Representation of generator dynamics

See point 3-7 of STRALE

3-8. Method of load flow computation

See point 3-8 of STRALE

3-9. Disturbance of that can be handled

See point 3-9 of STRALE

3-10. Analytical techniques for simulation

a. Simulation time range

Real-time simulation

b. Time steps

0.2 seconds

c. Numerical integration technique

Eucler explicit 1st order method

d. Model change

e. Frequency / voltage deviation

46-54 Hz; 0.7-1.3 KV p.u.

3-11. How to handle or actions of operator

On line by console

3-12. **Information from the program/simulator**

See point 3-5.b

3-13. **Initialization of program/simulator**

3-14. **Interface of program/simulator**

PPSS is automatically connected to the ENEL off-line digital program (typically the program STRALE) in order to have the necessary initialization.

3-15. **List of the reference(s)**

[1] Marconato,R., Marzio,L., Menditto,V., Ricci,A., User's experiences of a power system simulator, CIGRE SC 39 Colloquium, Power System Operation and Control, Tokyo, October 1987, Paper No. ST 87 11.

[2] Marconato,R., Marzio,L., Power system model for an operator training simulator, Report of W.G. 1/2 of CEGB-EDF-ENEL Collaboration, (September 1982)

[3] Maconato,R., "Simulations in tempo remle del comportamento statico e dinamico del sistemi di produzione e trasmissione dell'energia elettrica", Rassegna Tecnica ENEL, n.6, (1984)

[4] Marconato,R., Ricci,P.,"An outline on the prototype of real time power system simulator realized by ENEL,Report prepared for CIGRE S.C.39 T.F.03. (January 1987)

Application of the Developed Program/Simulator to Test Systems

4- 1. Outline of the test system

After the installation of the prototype by the National Control Center facilities, a lot of simulations have been performed,mainly with the target of verifying power system security during emergencies that have already happened or having some probability of occurring.

Due to the limits imposed by the computation resources available in the prototype, only parts of the ENEL system have been simulated.

In particular,three networks, each having 70 buses and 15 power stations, have been set-up: suitable equivalents have been adopted to represent the remainder of ENEL's network and of the European interconnected system. Nevertheless, on the simulated power system, which refer to the main 380 KV network and to those parts at 220KV having a fundamental transmission function, some problems concerning the lognitudinal structure of the ENEL system along the Italian peninsula, can be analyzed for a) Florence-Rome-Naples areas, b) Rome-Naples-Sicily region, c) Sardinia, respectively.

4-2. Condition and scenario in the simulation

The main simulations carried out had the main goals to verify:

1) the automatic load-shedding plan and the frequency behavior in the Sicilian network following a separation from the mainland with different imported power values before the isolation;
2) the frequency behavior of the same network that becomes isolated from the mainland while it is exporting 600 MW;
3) the voltages profile in the buses along the path of the Adriatic Coast as a consequence of active and reactive load increase with restricted generation capacity;
4) the network critical section with particular regard to voltage level caused by the unavailability of one or more lines and to the evaluation of maximum power which can be transmitted within static security limits;
5) the consequences of a bus-bar fault in absence of differential bus-bar protection.

4-3. Simulation results

See point 4-3 of STRALE

4-4. Consideration on the application result

See point 4-4 of STRALE

4-5. Validation methods

See point 4-5 of STRALE

Future Development/Improvement

5-1.Problems to be solved on the application of the program/simulator

None

5-2. Points to be improved in the future

None

5-3. Future development plans or new projects

None

Name of respondent(s), organization(s), country

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