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# ADVANCED ANALYTICAL TOOLS IN EVALUATING POWER SYSTEM DYNAMIC AND SECURITY PERFORMANCE – RESULTS OF A QUESTIONNAIRE

**Task Force 38-02-04 (Analytical topics)**
**of Study Committee 38 (Power System Analysis and Techniques)**

**March 1987**

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**Task Force 38-02-04 (Analytical topics)**
**of Study Committee 38 (Power System Analysis and Techniques)**


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# C O N T E N T S

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c) Give references to publications or applications of methods and tools.

## 1.3 CONTRIBUTORS

Replies to the questionnaire have been received from the following:

Australia and New Zealand (D.J. Hill)
(ETSA, SECV, NZE, HECT, ECNSW, SECWA, SMEC, QEC)

Belgium (A. Calvaer)
(CPTE)

Brazil (J.A. Jardini)
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Netherlands (J.H. Blom)

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South Africa (G. Mijne)
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United Kingdom (W. Fairney)
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United States of America (J.B. Prince, Jr.)
(Wisconsin Electric, NPPD, AEP, BPA, VEPCO, Boston Edison, Southern Company Services)

USSR (V.A. Stroev)

# S U M M A R Y

## 2. LOAD FLOW ASPECTS

### 2.1 ANALYTICAL TECHNIQUES

#### 2.1.1 State estimation

A great majority of the responses reports on strong interest in state estimation (SE). Many EMS Centers have already SE in operation, and many others are in a process of implementation. Two of the national replies stated that SE was not in use and presently not needed.

The given motivation for SE - which generally would seem to be based on a least square criterion, is the need for a more consistent and reliable basis for either real time operating decisions, post incidence and predictive analysis, or both. By predictive analysis is first of all understood activities relating to short-term operation planning, e.g. economic dispatch, interactive load flow, contingency analysis, etc. One participant also reports on SE as an appropriate tool in longterm planning, i.e. system design.

Many answers point to needs of improvement in current SE methodologies and schemes. Main proposed areas for further R&D activity:

- Increase of solution speed and computational stability of algorithms, particularly for large systems.

- Improve methods of detecting/rejecting bad data, including the differentiation between metering, structural and parameter errors.

- Improve modelling of external systems, including definition/interchange of related essential data.

- Use of dynamic methods under the changes in network structure and occurence of metering failures.

#### 2.1.2 Contingency evaluation and operators load flow

It was surprising how few EMS Centers, as compared to those in the U.S., use contingency evalution in operations and load flows with Real Time data. Most utilities have contingency evaluation and power flow functions implemented for operations planning purposes only, per the questionnaire. In fact, most utilities use power flow type techniques for contingency evaluation as well, but less than half report contingency evaluation implemented in real time, and even fewer have the operators load flow. Improvements desired are faster execution speeds, better and more user friendly programs, improved modeling, and more data input from neighbors.

- Near the voltage stability limits, multiple solutions occur and are very sensitive to load and generator modelling (Belgium).

Q-2 How can infeasible solutions be detected?

- By checking the load-flow output data by well-trained engineers (South Africa, Canada, UK partly, Brasil).

- By comparing the 1st solution (P-V specification) with 2nd solution (P-Q spec.) (Japan).

- Checking signs of dV/dQ or dV/dP (Japan, Brasil).

- By applying Security Criterion based on sensitivity coefficients (France).

- When both Gauss-Seidel and Full N-R methods fail to solve load-flow (Ireland).

Q-2(a) How to avoid or exclude infeasible solutions?

- By introducing "Supporting" generator nodes and imposing upper bounds on phase angles between certain nodes (USSR).

- By introducing two or more slacks (Siemens).

Q-2(b) How to check physical realizabillity of solutions?

- Checking by Steady-State Stability (USSR).

Q-3 Do multiple solutions occur due to the analyzing methods used or due to difficult network conditions?

| | |
|---|---|
| - Difficult network conditions | (Ireland) |
| - Analyzing methods | (South Africa, USSR (indirectly)) |
| - Both | (Canada, Australia) |

Q-4 May multiple solutions also occur by use of other analyzing methods, for example, State Estimation?

- No positive statement has been received, except Belgian system.

Q-5 Is power flow divergence a problem, and is it related to the occurrence of multiple solutions?

- Divergence is a great problem (Canada).

- Divergence and multiplicity seems to come from similar system conditions, e.g difficult network conditions (Japan, South Africa).

- Divergence and multiplicity are not related. (Brasil, New Zealand)

## 3.2 STEADY STATE STABILITY

### 3.2.1 Methods used and the state of the art

1. Among the 18 answers from different countries or companies, 4 said they have not tools for steady state stability evaluation. Their reasons for that are that the steady state stability limit is higher than the transient one, and that there is enough damping in their system. So they only perform transient stability analysis.

   It is believed, however, that care should be taken of the fact that some modes of lacking damping are not necessarily excited by limited case of faults.

2. There are 6 systems using the transient stability simulation program with small disturbances to analyse the steady state stability.

   Moreover, because this technique is very time consuming, 4 of the above systems use the eigenvallue method as well, for cases where the order of the involved matrices remains within tractable limits. Otherwise, the transient stability simulation program shows more useful.

3. The main method used by a half of the answers is eigenvalue method. The purposes of using it are:

   (1) For long term planning:
       (a) evaluating power flow limit of tie-lines
       (b) investigating schemes for improving steady state stability, e.g. placing PSS
       (c) identifying coherency
   (2) For operation planning:
       (a) evaluating power flow limit of tie-lines
       (b) setting the parameters of PSS and AVR

4. The other methods used are:

   (1) Laplace transform to compute transfer functions and step responsed functions, and to plot Bode or Nyquist diagrams.

       Note, however, that this method cannot provide information on sensitivity.
   (2) Algebraic method to study aperiodic instability phenomena.
   (3) Perturbed matrices method.

5. A few systems study steady state stability with dynamic equivalent. SSEB (U.K.) uses the rate of change of kinetic energy. France uses step response.

6. There are 4 systems which perform steady state stability analysis for their off-line operation planning. 3 of them use the same eigenvalue method as for long term planning.

7. No real on-line steady state stability analysis method has been used. Moreover, 3 systems (maybe others which did not mention, too)

containing errors, so the analysis method should be strong enough.

## 3.3 TRANSIENT STABILITY

### 3.3.1 State of the art

Out of 17 countries answering the questionaire, 15 are reporting that transient stability analysis are in off-line use for long term planning. Nine countries are reporting that transient stability analysis also are used off-line for operation planning. No real on-line transient stability analysis are carried out, but three countries (France, Italy, Japan) are indicating that "on-line like" transient stability studies are made in operation planning.

Many countries are developing their own programs for transient stability analysis, but nearly half of the answers indicate that standard software packages were bought from software houses.

The answers show that most of the programs have possibilities of detailed modeling of generators voltage regulation, turbine and speed-governor functions, and frequency and voltage dependent load models. Other models specially developed are

* Induction motors
* HVDC and control functions
* SVC and control functions
* Protection relay functions
* Three phase models
* Load shedding

### 3.3.2 The need of transient stability analysis

It is reported that transient stability analysis are needed for studies of

* System performance under failure conditions, such as short circuit and load shedding
* Power transit limitations
* Special transmission condition
* New lines
* Connection of new big power plants
* Voltage regulation functions
* Protection scheemes
* Control functions and control actions
* Parameters of new components, such as generators, transformers, etc.
* Power system stabilizers and SVC equipment
* After fault verifications

solution of problems within this field of large scale disturbance analysis.

The enquiry gives a mixed impression as to the present use of, respectively the need for developing LTS programs. Most responses give answers to the effect that LTS-type problems are solved by the use of standard or adapted TS-programs, and many of these users apparently see only a limited motive for developing new LTS-schemes. Other utilities within this user group see a need for further program development and are working on/proposing schemes that will make existing TS programs more efficient, provide a more correct modelling, and/or integrate TS and LTS. A few utilities report on having dedicated tools for LTS. Present practice seem to indicate that LTS is conducted first of all within the context of longterm planning, but also within operation planning.

In general R&D activity would seem to be desirable within two main areas:

- Improved modelling of crucial elements/local processes such as boilers, nuclear reactors, transformer tap changing, power plant control and protection systems, and

- improved integrated handling of the stability problem, i.e. optional handling of TS or LTS.

GERMANY:
- Operation planning:
  In use.
- Operation real-time:
  In use [10]-[11]

IRELAND:
- Operation planning:
  SE is being implemented primarely as a basis for deriving starting conditions for other analysis programs.
  A procedure for bad data rejection will be applied, but it is not foreseen that topology errors could be corrected automatically by SE

- Operation real-time:
  A new National Control Centre is in construction, and SE is one of the extended real-time functions.

ITALY:
- Operation real-time:
  SE is in the process of being implemented in the new centralized Control System of ENEL. An off-line program based on the WLS-method has been used for some time for R&D purposes, providing the foundation for the on-line SE. [12]-[14]

JAPAN:
- Not in use.

ROMANIA:
- Operation real-time:
  Implemented within the National Dispatching Board. Based on telemetered power flows through the lines.

SOUTH AFRICA:
- Long-term planning:
  Not in use and not planned for in the near future.

- Operation planning:
  The need for SE as a basis for planning studies is realized, and implementation is under way. The full Newton-Raphson state estimation technique will be used. An offline SE-program is presently used to aid in preparing the power network for the on-line SE. (To improve instrumentation.)

- Operation real-time:
  Planned for in the near future. Main motivation; to have better information to make real time operating decisions on.

UNITED KINGDOM (CEGB):
- Long-term planning/Operation planning/Operation Real Time:
  SE is implemented/to be implemented mainly for operation planning and operation real time purposes. CEGB has SE installed. NSHEB is in the process of implementing SE on the 275 kV transmission system. NIES will follow suit (1988).
  SE is considered to involve three main functional features (CEGB).

  Topology Validation:
  In use for some time, but covering only main system switchgear. Switchgear associated with reactive compensation is not covered. Improvements required.

GERMANY:

- Operation planning:
  Better description of the influence of surrounding networks.

IRELAND:

- Operation real-time:
  Increase solution speed "to real time". (It is believed that this would be attained by more computing power, parallell processing, etc. - rather than by a superior algorithm.)

JAPAN:

- Operation real-time:
  For the improvement of execution time on on-line load flow, the use of SE is under investigation (TEPCO).

ROMANIA:

- Operation real-time:
  Improve quality with respect to:
  - handling of large errors/bad data
  - handling of low redundancy
  - accounting for the states of neighbouring power systems.

SOUTH AFRICA:

- Long-term planning:
  Further R&D should be contemplated since SE potentially could be a useful basis for:
  - Elimination of bad data used in longterm planning
  - Network parameter verification/estimation
  - External network equivalent estimation-

- Operation planning:
  The SE should indicate a confidence level for each measurement based on historical and present data.

- Operation real-time:
  The SE should supply itself with "pseudo-measurements" when the system becomes unobservable. The SE should probably be a dynamic SE. The Se should be faster, perhaps by using decoupled SE-techniques.

UNITED KINGDOM:

- Long-term planning/Operation planning:
  Improve Topology Validation by including reactive compensation in the process.

  Improve Gross Measurement Error Detection (data validation) by including reactive power measurements in the process. Include the feature of Error Minimization by adequate redundancy of measurements.

U S A:

- Operation real-time:
  Differentiating between metering and structural errors.
  External models. Transfer of essential data from external systems.
  Direct phase angle measurements.
  Evaluation of most efficient method of SE for large systems.
  Optimal level of measurement redundancy.

U S S R:

- Long-term planning:
  Increase speed and computational stability of SE static algorithms.

U S A:
- 24 of 74 USA systems use contingency analysis (1984)
  Linear and full LF methods used.
  Contingency list
  Violation check list.

#### 4.1.2.2 Needs of improvements

AUSTRALIA/NEW ZEALAND:
- Extend to use in real time.

BRAZIL:
- None required.

DENMARK:
- No need to improve.

ITALY:
- Introduction of secondary voltage control?

NETHERLANDS:
- Add contingency screening and implement in EMS.

ROMANIA:
- Modelling or postcontingency conditions:
  1. Reallocation of gen. P.Q.
  2. Hypothesis of unique slack bus.

UNITED KINGDOM (CEGB):
- AC contingency evaluation as part of security enhancement.

UNITED KINGDOM (Scotland):
- Postcontingency modelling:
  1. Redistribution of power.
  2. AVR control of generations.
  3. Analysis of split system.

U S A:
- Automatic ranking algorithm
- Inclusion of dynamics
- Inclusion of frequency & duration of contingencies
- Real-time equivalents
- Preventive action

### 4.1.3 Operators load flow

#### 4.1.3.1 State of the art

AUSTRALIA/NEW ZEALAND:
- Fast decoupled N-R.

BELGIUM:
- Interactive load flow used.

CANADA (Hydro Quebec):
- Not used.

Operation Planning:
No present application.

ECNSW may consider a program which represents the transmission system and includes boiler/turbine response. Operations in NZE intend using the EPRI Transient Mid-term Stability Program to simulate "mid-term" instabilities and determine suitable governor/exciter/power system stabiliser settings which prevent them. Also this analysis will establish suitable spinning reserve, simulate the effect of AGC (soon to come on-line) and verify the effect of under-frequency relay settings.

Operation Real Time:
No present/planned for application.

Additional information:

- Needs of long term stability analysis.
  NZE (looking to future extensive use) states its needs clearly as principally to identify the correct dynamic matching of load and generation with a view to thermal plant operation, spinning reserve requirements, load shedding policy, PFC on HVDC, AGC etc. (see above). The coordinated dynamic response of these must be well planned to allow economic and secure system operation. The somewhat less needs of other authorities have also been covered to some extent in the above sections; the most stated one being checking performance of load shedding schemes. SMEC aims its long term analysis at determining MW response requirements from new power stations.

- Modelling of prime mover, energy supply and load balance.
  NZE prime mover models are based on IEEE standards in both programs. The EPRI Program energy supply (boiler) and load balance (AGC) models are described in above references.

CANADA:

General:
This aspect of stability is treated the same way as transient stability.

BELGIUM:

General:
A "generalized stability" program is presently in elaboration. It would be able to study the transient, mid-term and long term behaviour of the system. It will be based on improved mathematical methods of variable integration step for the transition from rapid transient phenomena to slow mean values oscillations. (Implicit ordinary differential equations solved with control of order and step size taking advantages of simultaneous solution of differential and algebraic equations).

The main needs are:

1. improved modelling of loads (induction motors ...), broad band

U S A:
- Expand PGM to include external system
- Inter utility data exchange.

#### 4.1.4 Sensitivity analysis

##### 4.1.4.1 State of the art

AUSTRALIA/NEW ZEALAND:
- Successive load flow plus inverse Jacobian.

CANADA:
- Not used.

FINLAND:
- There is a need but not available.

IRELAND:
- Not used as such, only to obtain constraint line sensitivities with gen. dispatches for reallocating generation.

JAPAN:
- Inverse of Jacobian used, and simplified Jacobian.

ROMANIA:
- Inverse of Jacobian and eigenvalue matrix.

SOUTH AFRICA:
- Not used.

UNITED KINGDOM (CEGB):
- From inverse Jacobian.

U S A:
- Used for both long term and operations planning.
  Sensitivity factors:
    Line outage response
    Generation shift response
    Area power transfer response
  Linear and non linear LF used.

U S S R:
- Inverse of Jacobian matrix terms.

##### 4.1.4.2 Needs of improvements

AUSTRALIA/NEW ZEALAND:
- Incorporate in real time.

ROMANIA:
- Considerable computational effort required.

SOUTH AFRICA:
- Future need.

UNITED KINGDOM (Scotland):
- Not used.

U S A:
- Generally not available, but a subject for research.
  3 of 74 USA control centers have optimal power flow.
  Some utilities seek suboptimal power flow through iterative power flow runs.
  All utilities that replied find inadequacies in existing methods.

U S S R:
- Reduced gradient method with penalty functions (probably similar to Dommel-Tinney approach).

#### 4.1.5.2 Needs of improvements

AUSTRALIA/NEW ZEALAND:
- Active power part needs to be incorporated.

BRAZIL:
- Expanding program to at least 100 buses.

DENMARK:
- Methodology insufficient for future (no reason given).

FRANCE:
- 3rd generation being developed including security constraints and greater speed.

ROMANIA:
- Convergence problems.

U S A:
- Continued research.

U S S R:
- Faster optimization methods, randomness recognition.

### 4.1.6 Stochastic load flow

#### 4.1.6.1 State of the art

AUSTRALIA/NEW ZEALAND:
- SLF is not used. Overall there are no concrete proposals to use SLF.NZE, SECWA, HECT see the concept as attractive with only NZE likely to consider its development in long term planning.

BELGIUM:
- Program for SLF has been developed [34]. This probabilistic load flow program is used for planification studies of the Belgian electrical system. It detects the branches of this network which may be overloaded. Moreover, it provides a global value of the network loading.

  The advantage of this program compared with usual load flows is to

SOUTH AFRICA:
- No needs foreseen.

U S A:
- SLF needed to analyze data inaccuracies. SLF may prove useful for probabilistic planning.

U S S R:
- Improve applicability of statistical approximation method (SLF) by devising faster solution techniques and reducing memory requirements.

## 4.2 MULTIPLE SOLUTIONS

### 4.2.1 State of the art

AUSTRALIA/NEW ZEALAND:
Background:
- This problem never occurs for many authorities and only ever rarely. Indeed, SECWA has had cases due to the natuare of P vs V curves for different Var compensation levels. In QEC it does occur on radial parts of the network, being dependent on load modelling to a large extent. SECV have encountered it in the analysis of a particular area for line outage and extreme contingencies.
- In all of 5 authorities multiple solutions are generally obvious from voltage and $Q_G$ levels.

Thought and Experience:
- Multiple solutions are due to a combination of analyzing methods and difficult net conditions (ESTA, NZE, QEC, SECWA). They are due to difficult net conditions (SECV).
- Occurrences of multiple solutioins are only in load flow to date.
- Divergence (low voltage on radial parts of network) is reported only by NZE. Not normally related to multiple solutions.

BELGIUM:
Background:
- Multiple solution problem has not been investigated for itself. But some related phenomena have been experienced frequently where the final solution of state estimation often depends on the starting point.

Thought:
- Bad voltage distributions (profile) may be experienced during fast loading variations of the system due to unsuitable Var sources operation.
- Near the voltage stability limits, multiple solutions occur and are very sensitive to load and generator modelling.

BRAZIL:
Background:
- In the planning studies, multiple solutions rarely occur.
- Infeasible solutions would all be detected by a well trained analyst. Such solutions may lead to (i) extremely large Var output

GERMANY:

Thought:
- Multiple solutions and difficulty with convergence both occur only when extremely difficult and technically not realizable network conditions are to be calculated in the planning phase. (Deutsche Verbundgesellschaft)

GERMANY (BBC):

This problem has not been important in our investigations.

GERMANY (SIEMENS):

Background:
- This is not a problem.
- Difficulty with convergence can be avoided by introduction of two or more slacks.

IRELAND:

Background:
- This is not a large problem. It could become a problem if free tap-changing were allowed in LF studies.
- Infeasible solution is considered to exist if both Gauss-Seidel and full N-R methods fail to solve load flow. Relaxing limits will usually produce a solution.

Thought:
- It is felt that the network rather than solution algorithms, lead to infeasible solutions.
- Insufficient experience to comment on relationship between state estimation and multiple LF solution.

ITALY:

This is not a great problem.

JAPAN:

Background:
- N-R method and P-Q decoupled LF developed by CRIEPI are in use, both of them not provided with devices against ill-conditions. Most utilities have interest in this problem, but have no computational experience except TEPCO where they suspect rare possibility of occurrence in case of line outages, e.g.
- Infeasible solutions are detected by (i) comparison with existing LF, (ii) comparing 1st solution (P-V spec.) with 2nd solution (P-Q spec.), Q being obtained from 1st solution (P-Q spec.), (iii) checking signs of dV/dQ or dV/dP.
- LF divergence and multiple solutions: It is commonly understood that system condition causing divergence and that causing multiplicity have common features, one-to-one corespondence between the two being uncertain, though.

As replies were written (summarized) based on those from utilities only (not from University), the statement in this column has not direct connection with the references.

changing the slack busbar.

- NSHEB (without any long capacitative circuits or extensive cable networks):
  Experience shows that load flow convergence to a solution is obtained once the Var imbalance is resolved.
- SSEB:
  Divergence, on rare occasions, is related to Var compensation requirements at light load.

U S S R:

Background:

- Problem of multiple solutions appeared in mid 60's during optimal load flow w.r.t. voltages Var injections and tap ratios.
- Analysis of a 2-node system has shown that existing load flow methods with $P_G$ and $Q_G$ specified led to the solution with high voltage levels, a permissible solution also existed, the latter being unstable.
- Specification of $P_G$ and $V_G$ has led to the multiplicity of load flow solutions with different $Q_G$. The existing load flow methods converged to the 1st permissible solution, while the 2nd solution with inadmissible high $Q_G$ was found unstable. Calculations for large systems confirmed conclusions derived from 2-node system.
- Introduction of "supporting" generator nodes [52] practically excluded multiplicity problem in load flow optimization. "Supporting" nodes are chosen in such a way that phase angles $\sigma_{ij}$ between any unsupporting or load nodes(j) and nearest supporting node(i) should not exceed 30-35. Physical realizability is checked by steady-state Stability.

### 4.2.2 Needs of improvements

CANADA:

- Load flow divergence is actually a great problem. It is related to difficult network conditions.

GERMANY:

- Load flow algorithms in the future should be able to use generator and load models of static type instead of P-Q or P-V node spec. So that Q vs V characteristics be better described.

SOUTH AFRICA:

- Algorithm is needed to solve both divergence and multiplicity by checking input data and pin pointing weak areas in the network.
- Load modelling needs more research.
- A proper choice of constant P constant Z transition voltage forces a 2-bus system to have one and only one solution. This technique might be expanded to larger, more complex systems.

FRANCE:

Off-line studies:

- Two programs are mainly utilized:
  1. The COMPENS program (see the paragraph on multiple solutions) which includes the $dQ_{gen}/dQ_{load}$ sensitivity criterion. This program tries to optimize the reactive power generations, the shunt compensation and the tap changers on the basis of an objective function which is a combination of voltage deviation from the maximum in each node and the cost of added compensation.
  2. The CODYSIL program [57] simulates the behaviour of the system over several tens of minutes including speed governors, LFC, secondary voltage control, tap changing.

On-line studies:

The COMPENS program is now used in control centers a day ahead.

GERMANY:

- It is mentioned that the NETOMAC program is able to verify the voltage stability and both steady-state and transient stabilities.

IRELAND:

- No problem.

ITALY:

- Both for planning and operation purposes, the voltage stability is normally non critical for the ENEL power system.
- In any case it can be analyzed by means of:
  - computation of the system eigenvalues (see steady state stability)
  - simulation programs relevant to medium or long term dynamics.

JAPAN:

Off-line, long-term planning:

- PQ decoupled load flow, Newton-Raphson and dV/dQ methods are used for AC systems; eigenvalue method is used for DC systems.

Off-line, operation planning:

- Newton-Raphson is used to investigate scheduled outage planning and operation planning in both heavy and light load conditions.

On-line, operation real-time:

- Newton-Raphson method is used to evaluate PQ balance of large cable systems in case of isolated operation (TEPCO).

JAPAN:

- The voltage distribution is always checked when networks are calculated, also for failure cases.

ROMANIA:

- The voltage instability is considered as a revealing form of the steady state instability in particular conditions.

(This formula has been derived under the assumption that transformers with tap changers are connected between the bus and terminals of electrical installations).

3. Power system operation is performed in such a way that the voltage stability margin $k_V$ satisfies the following inequalities:

$$k_V = \frac{V - V_{cr}}{V} \geq \begin{cases} 0.15 \text{ in normal conditions} \\ 0.10 \text{ in post-fault or very heavy conditions.} \end{cases}$$

### 5.1.2 Needs of improvements

AUSTRALIA AND NEW ZEALAND:

Off-line studies - long term planning:

- There is a general agreement between utilities on the need of improvements but the ways seem quite different: HECT (Tasmania) is interested by the method described in [54]; QEC (Queensland) pursues researches on an improved stability index, and SECV (Victoria) plans to use assessment via sensitivity and contingency analysis.

Off-line studies - operation planning:

- ECNSW (New South Wales) requires systematic checking for a critical contingency and determination of operating margin using dQ/dV criterion.

On line studies:

- SECV propose post contingency checking as part of contingency evaluation.

BELGIUM:

Long term and operation planning:

- In spite of the fact that the $U/U_o$ criterion is very useful, a more sharply discriminating criterion is wanted.

BRAZIL:

- No.

CANADA:

Long term and operation planning:

- Most of the studies deal with finding a proper solution to overcome the problem described in the column "State of the art".

DENMARK:

- Methods are expected to be introducted in the future.

FINLAND:

- Some kind of voltage collapse indicator is needed in operation planning.

FRANCE:

- Development of algorithms for tertiary voltage control (optimum voltage profile).

disconnections of large motors;
- rapid restoration of normal operation of industrial plants after instability of the motors.

## 5.2 STEADY STATE STABILITY

### 5.2.1 State of the art

Off-line studies, long term and operation planning:

AUSTRALIA/NEW ZEALAND:
- Transient simulation program was used by a few systems.
- Eigenvalue method is the main method.
- Other methods are frequency domain methods.
- In operation planning eigenvalue method is used.

BELGIUM:
- Eigenvalue method:
  Classical state variable approach (DYNOS).

BRAZIL:
- Not available.

CANADA (Hydro Quebec):
- Not available.

DENMARK:
- Eigenvalue method is used.

FINLAND:
- Not available.

FRANCE:
- Other methods:
  1. Laplace transform; Bode diagram to improve AVR.
  2. Determine coherency.

GERMANY:
- Transient simulation program is used.

IRELAND:
- Transient simulation program.
- Eigenvalue method: Considering the whole system state.

ITALY:
- Eigenvalue method is used.
- Other methods are: Perturbed matrix method, place PSS and choose their gains.

JAPAN:
- Transient simulation program and eigenvalue method:
  1. Evaluating LF limit of tie-lines.
  2. Investigating schemes for improvement.
- Operation planning:
  Evaluating load flow limit of tie-lines.

1. faster
2. sensivity analysis
3. direct method to calculate dominant eigenvalues.

- For others:
  1. more efficient analysis methods
  2. stochastic stability evaluation to frequency domain technique.
- For operation planning:
  fast direct technique for selection of the critical eigenvalue.

BELGIUM:
- For eigenvalue method:
  Extend it up to 500 or 1000 variables and improve the load model.

FINLAND:
- For eigenvalue method this maybe purchased.

FRANCE:
- For operation planning:
  New tools to check the stability.
  Estimating the impedance seen from the generator.

IRELAND:
- For eigenvalue method:
  Improving the models of load, exciter and governor.

ITALY:
- For eigenvalue method:
  Improve the models of load, SVC and HVDC.

JAPAN:
- For eigenvalue method:
  Fast, including motor load.

SOUTH AFRICA:
- For eigenvalue method:
  To be used to calculate the optimum corrective action.

UNITED KINGDOM:
- For eigenvalue method: Including more than one PSS.
- Operation planning: Sensitivity analysis.

U S A:
- Eigen input from TS database.
- Theory on required model complexity.
- White noise input for TS program.

<u>On-line studies</u>:

FRANCE:
- Simplified criteria is needed.

U S A:
- Theory and methods for mode identification.
- Estimation of modes from disturbance records.
- On-line performance assessment and acceptance criteria.

ITALY:

- Transient stability analysies are carried out both for planning and operation using the computer program named NEWDYN [106-111].

JAPAN:

- In long term planning and operation planning a detailed simulation method developed by CRIEPI is commonly used for investigation of operation limits and stability control methods. Models of synchronous machines, generator controllers, AC-DC converters, nonlinear load characteristics an protection realys are included. [112-114]

THE NETHERLANDS:

- Not carried out at present time.

ROMANIA:

- Transient stability analysis are in use to study short-circuit effects. The simulation interval is within a few seconds. Generators are represented by simplified models. Loads are modelled by impedances. Induction motors can be represented. The control functions of the generators can be represented in detail. System areas far from the fault points are represented by equivalents. [115-117]

SOUTH AFRICA:

- Short term stability programs are in use. Detailed modelling of machines and loads can be done, but is not really of much use because actual load data is not available. Transient analysis are carried out for symmetrical faults only. [120-127]

UNITED KINGDOM:

- Transient stability analysis are carried both for long term and operation planning. Different power system analysis packages are used [128-130]. Detailed modelling is possible for generators, excitation and speed-governor control systems. Synchronous motors and condensers may be represented and dynamic models of induction motors. Both fixed impedance laod representation and voltage dependent laod models are in use. The integration of the differential equations is performed either by an explicit trapezoidal method, or by 4th order Runge Kutta method with variable step length.

U S A:

- Most utilities use conventional TS program for long term and operational planning:
  - Detailed machine models for local machines
  - Classical models for remote machines
  - Up to 4000 buses, 800 branches, 1400 machines
  - HVDC available on most programs

U S S R:

- Transient stability calculations are performed in long term planning. Computer programs can handle power systems of 300 nodes, 450 branches and 100 generators. Simplified Park's equation model of generators is used, and automatic excitation regulation and simple model of speed governor is adopted. Induction motor model is available [138-139].

conditions to allow rapid determination of limity transfers is required by one company [92-96].

BELGIUM:
- The need of better technical information between neighbouring countries of the UCPTE appears.
- Important theoretical investigations about Lyapunov method and stability indexes are carried out [97-101].

CANADA (Hydro Quebec):
- Faster solution methods.
- Possibilities of pocessing the output data of a standard stability test to obtain significant relationships between system state variables in order to ease the interpretation of the results.
- Need of efficient programs with detailed models of the equipment because the system is very sensitive to equipment characteristics, especially the control systems of generators, compensators and HVDC.

FINLAND
- Detailed network, generator, excitation control, turbine governor and load modelling is needed.
- Parameter setting in dynamic models.

FRANCE
- Take into account greater networks because of strong interconnections between France and its neighbouring countries.
- Good dynamic equivalents
- Global stability index could be useful to select interesting situations.

GERMANY
- Better models for generators, voltage control functions and turbine governors [104].
- Eigenvalue calculations

IRELAND
- Increased solution speed would be of help in increasing the volume of analysis that could be carried out.
- Better data for loads and control systems
- Better load models

ITALY
- Experimental tests to identify some composite loads.
- Implementation of the models of different type of SVC and Multi-Terminal HVDC networks and their controls.

JAPAN
- Speed-up of detailed simulation method is necessary

THE NETHERLANDS
- Studies will be initiated to deal with possible stability problems in the future network.

ROMANIA
- Methods for parallell solution of transient problems and fast determination of stability regions are promising methods for further investigations [118-119].

SOUTH AFRICA
- Accurate load modelling is necessary, but that needs more research

U S A:
- Method for determing transfer limits that preserves dynamic security

## 5.3.3 Additional information

### 5.3.3.1 Describe the needs of transient stability analysis in your power syste

AUSTRALIA and NEW ZEALAND:
- Transient stability analysis (TSA) needed to study power transfer between large generation and load centres. TSA also nedded to determine excitation control system parameters and requirements for transmission line protection scheemes.

FINLAND
- Transient stability simulations are necessary both in long term planning and in operation planning to determine the transmission capacity limits in the Finnish system and the whole Scandinavian interconnected system (Nordel-system) with respect to certain dimensioning criteria [102].

FRANCE:
- E.D.F. network is planned to overcome without major problem a three phase fault (normally cleared) on any line.
- Transient stability is often checked for a double three phase fault
- Transient stability analysis are made before special planned for transmission conditions are set into operation.

GERMANY:
- Transient stability analysis necessary when connecting new power plants $\geq$ 600 MW to the network.

IRELAND:
- Transient stability analysis are used mainly at the planning stage to determine
  * requirements for transmission circuits to planned generating stations
  * requirements of circuit breakes and protection relays to maintain stability
  * requirements for stabilisers/static VAr compensation
  * large industrial consumers require information on voltage dips and their duration during faults.

ITALY:
- Transient stability are needed in planning for
  * verifying the impact of new power plants, new lines etc.
  * defining and up-dating the most suitable load-shedding plans
  * changing the philosophy of the operation of the distance protections
  * verfiying the influence of suitable controls to avoid loss of synchronism of generators or parts of the system
- In operation transient stability analysis are used for
  * defining the exact sequence of the events during a failure and verifying the behaviour of control and protection equipments
  * verifying the system dynamic model
  * finding corrective measures in the system to avoid repetition of failure events or to limit their effects

IRELAND:
- Following a low or zero impedance, two-or three-phase fault close to a generating station or to a bulk supply point and cleared by first-step protection there are requirements of no network islanding, no pole-slipping and no voltage collapse.

ITALY:
- Transient instability is characterized by out-of-step of one or more synchronous generators.

SOUTH AFRICA:
- If all generator angles seem to experince damped oscillations then it is assumed that the system is in a condition of transient stability. In some instances busbar voltages are used to determine the stability of the system.

UNITED KINGDOM:
- First swing stability
- Reasonable damping over multiple swings

5.3.3.3 Describe the modelling needed

FRANCE:
- Loads are modelled as constant impedances, damping winding and saturation are modelled for generators. Excitation control system, speed governor and turbine are modelled in detail.

GERMANY:
- Generators are modelled by Park's differential equations for d-and q-axes. Voltage regulators and turbine regulators are modelled by transfer functions, an nonlinearities are modelled specially.
- Loads are mostly modelled as constant P-Q-input or as constant impedances, but frequence and voltage dependent load-models are developed, and also models for asynchronous motors.

IRELAND:
- Generators near the fault area have detailed modelling as well as the modelling of voltage regulators and speed governors.
- Load must have both static polynomials (P/V, P/f, Q/V, Q/f) and it must be possible to represent induction motor reactances, saturation and the speed/torque-characteristics of the drive as a polynominal.
- Network Reactive elements must be frequency dependent, and SVC devices must be possible to represent in detail.

ITALY:
- Synchronous machines are represented from 2nd to 6th order dynamic models, excitation system and voltage regulators (with four main models), speed governors and prime movers.
- Loads are represented linear and nonlinear depending on both frequency and voltage .
- Load shedding devices depending on frequency and time derivative
- Line distance protections are modelled
- Parts of the system far from the considered perturbations are modelled by dynamic equivalents that are established by a systematic procedure.

JAPAN:
- For synchronous machines a Park model with characteristics of flux saturation

remote from the fault.

ITALY:
- Simplified modelling (2nd order machines) may be satisfactory for first assessment only for off-line planning purposes or for on-line simplified analysis.

JAPAN:
- Xd' model of synchronous machines is not good enough, and power system reduction for a multi-machine system should be made carefully
- Excitation systems, governors and power systems remote from a disturbance point are represented by simple models but those close to the point are represented by detailed models
- Impedance load representation is not adequate.

SOUTH AFRICA:
- Simplified modelling is good enough for first assessment

UNITED KINGDOM:
- Simplified modelling is good enough for first assessment, but invariably the final assessment is made using the detailed model

5.3.3.5 Comment on possible conflicting interests met in handling of transient stability and other types of stability aspects, such as steady state stability, voltage stability, etc.

AUSTRALIA and NEW ZEALAND:
- Fast excitation systems to improve transient stability conditions can have undesirable effect on long term stability.

CANADA (Hydro Quebec):
- There are conflicting interests in handling of different types of stability aspects.

FRANCE:
- Voltage stability can effectively conflict with transient or static stability
- Between transient stability and steady state stability there is no real problem.

GERMANY:
- Fast voltage regulators have positive influence on transient stability, but have negative influence on damping oscillations.

IRELAND:
- Conflicting interests arise in the area of excitation of generators. High rate excitation is beneficial in the case of transient stability but reduces the steady state stability of the generators somewhat. Otherwise there is no awareness of conflicts.

SOUTH AFRICA:
- Only transient stability studies have been done, and no special programs to handle other kinds of stability. So no conflicting interests were met.

Operation Planning:
No present application.

ECNSW may consider a program which represents the transmission system and includes boiler/turbine response. Operations in NZE intend using the EPRI Transient Mid-term Stability Program to simulate "mid-term" instabilities and determine suitable governor/exciter/power system stabiliser settings which prevent them. Also this analysis will establish suitable spinning reserve, simulate the effect of AGC (soon to come on-line) and verify the effect of under-frequency relay settings.

Operation Real Time:
No present/planned for application.

Additional information:

- Needs of long term stability analysis.
  NZE (looking to future extensive use) states its needs clearly as principally to identify the correct dynamic matching of load and generation with a view to thermal plant operation, spinning reserve requirements, load shedding policy, PFC on HVDC, AGC etc. (see above). The coordinated dynamic response of these must be well planned to allow economic and secure system operation. The somewhat less needs of other authorities have also been covered to some extent in the above sections; the most stated one being checking performance of load shedding schemes. SMEC aims its long term analysis at determining MW response requirements from new power stations.

- Modelling of prime mover, energy supply and load balance.
  NZE prime mover models are based on IEEE standards in both programs. The EPRI Program energy supply (boiler) and load balance (AGC) models are described in above references.

CANADA:

General:
This aspect of stability is treated the same way as transient stability.

BELGIUM:

General:
A "generalized stability" program is presently in elaboration. It would be able to study the transient, mid-term and long term behaviour of the system. It will be based on improved mathematical methods of variable integration step for the transition from rapid transient phenomena to slow mean values oscillations. (Implicit ordinary differential equations solved with control of order and step size taking advantages of simultaneous solution of differential and algebraic equations).

The main needs are:

1. improved modelling of loads (induction motors ...), broad band

GERMANY:

General:
LTS is applied within the context of longterm planning. Such studies are particularly relevant to sub-systems with a dominant share of thermal generation, following a disconnection from the main grid. In cases of sudden surplus of power, the control gear must be designed to cope with that problem. In cases of power deficiency, sufficient secondary reserve must be available together with schemes of load shedding. In LTS, turbines are modelled individually. To each point in time the equilibrium condition between total active load and total turbine power generation is established, and from this the (sub)system frequency is derived.

Needed improvements; Simple but adequate description of power turbines and associated control gear, and relevant dynamical description of loads.

Additional Information:
- The program is used first of all for basic scenario studies and for special parameter sensitivity analysis. It is used less for practical operation planning.

- The application of LTS is given by the need for investigating:
  - Voltage-, frequency- and power balance conditions following loss of plant(s) or disconnection of tie-line(s) leading to islanding.
  - Control responses of power plants following the stated types of "events".
  - The influence of the load on voltages and frequency, including effects of load shedding schemes.

- Modelling remarks specific to LTS:
  - Simplified generator models are used (neglecting subtransient phenomena).
  - Simplified turbine-/block control schemes.
  - Single phase network description.
  - Voltage- as well as frequency dependent load description.

IRELAND:

General:
The timescale for long-term stability extends for some 10 s. Following loss of a large generator the frequency falls to about 48.5 Hz and the fall is arrested, in 5-6 s by spinning reserve and sometimes by automatic load shedding, followed by automatic load restoration. Boiler dynamics, other than reheater dynamics, are rarely a factor except that in the case of once - through boilers severe drop in pressure may trigger safety devices. Spinning reserve is carried mainly by a pumped storage station but also by steam plant and gas turbine plant.

Long term stability is investigated by simulation, where mechanical systems only are represented. The biggest single problem is the complexity of plant control systems which appear to react in quite a different manner in similar circumstances. Main reasons for this: different settings by operators of plant setpoints and limitations due to minor plant problems, which are not very significant in steady

Additional Information:

1) Needs of analysis:
Apart from some needs very similar to the ones described above, it is worth to mention the analysis of the dynamic behaviour of thermal units and of their relevant controls in response to large perturbations.

2) Modelling:
The modelling is the one considered in the digital program STRALE. All the phenomena associated with the electromechanical oscillations and with the transients concerning the primary voltage control loops are completely disregarded. More precisely, with reference to the medium-term dynamics, the contribution of the system-eigenvalues due to electromechanical oscillations, field circuits, damper circuits, voltage regulators is neglected: only the mean frequency transient is considered. Moreover referring to the classical transient stability studies, one takes into account only the consequence of a fault, that is a line opening, a generator tripping and so on, and not the fault itself.

The goal of such a program is the simulation of the power system dynamic behaviour relevant to the "slow transients" associated with the following phenomena:
- the primary frequency control,
- the behaviour of the supply systems and of the prime movers,
- the load-frequency control (or secondary frequency control),
- the power boosting,
- the secondary voltage control,
- the intervention of the over and under excitation limits of the units,
- the action of the on-load tap-changers,
- the action of overload relays, under and over frequency relays, under voltage relays.

With specific reference to supply systems and to prime movers of thermal units, the models are described with a very high detail taking into account the frequency bias, the speed governor, the power regulator, the boiler and the superheater, the admission pressure and firing controls, the valve control, the HP and the MP-LP stages of the turbine.

JAPAN:

Longterm Planning:
Simulation methods including dynamics of thermal and nuclear (PWR, BWR) power plants are used for one to two minutes phenomena mentioned below under "Additional Information".

It is necessary to improve the simulation methods of power plant dynamics.

Operation Planning:
Comments as above.

Operation Real Time:
No specific need for long term stability program; the operation planning results are used for doing real time operation.

Additional Information:
No long term stability program is in use in ESCOM now. ESCOM is investigating some programs for determining spinning reserve requirements, generating plant response and frequency behaviour on loss of generation. Two possibilities are EPRI's LOTDYS and CEGB's CUTLASS.

UNITED KINGDOM:

Longterm Planning:

CEGB: [155,156]
Generating plant with similar characteristics are grouped together with several types of generating plant being modelled so as to cover regulating and non-regulating, reheat or non-reheat steam plant, hydro plant including pumped storage and gas turbine plant. The model includes system inertia and provision for including a load/frequency characteristic. The application of low frequency load disconnection relays can also be simulated. The program does not include representation of the electrical network so that voltage dependent effects including magnetic saturation cannot be studied. A program based on the above with the addition of the network being modelled by two busbars with a single interconnecting circuit has been used to study voltage dependent effects.

A more extensive multi-node, multi-circuit program is to being developed to enable more realistic investigations to be carried out of voltage and frequency variations following major system disturbances.

NIES:
A program developed by NIES is used at present to investigate spinning reserve problems which are apparent on a small system with some relatively large generating units. The program is: (i) off-line (ii) the boiler is not modelled (iii) the generators are lumped together with a common droop characteristic (iv) the turbine, generator and load inertias are lumped (v) the transmission system is not modelled (vi) system load is varied with frequency (vii) reheat and non-reheat time constants are represented and (viii) load shedding is modelled.

A new off-line program is being developed which will attempt to model: (i) individual biolers and turbo-generators (ii) a lumped transmission system and (iii) variation in system voltage and hence change in system load with both voltage and frequency.

NSHEB: [157,158]
Long-Term Planning Studies have been carried out for some of the isolated island groups currently supplied from diesel generation and where there is alternative energy generation being introduced or proposed. The inherently random nature of the output from aerogenerators or wave power generation creates difficulty in maintaining frequency and voltage. A program is used which provides a detailed dynamic simulation of the diesel generating plant, the system and alternative energy generation.

U S S R:

<u>General</u>:
Long term transients in power system include 3 stages. At the first stage the processes are determined which characterize relative oscillations of the generators' rotors. Frequency variations influenced by speed governors action are characteristic of the second stage. The third stage is determined by thermal-mechanical transients, power-frequency control action and by the operation of "fast" reserve. The boundaries of different stages are not sharp. The transients may return from the second and the third stages to the first one under the occurence of disturbances.

The main problems are: specification of the structures of power system components models for various stages of the process, development of criteria for the choice of efficient power system models and their simplification, the choice of efficient methods of processing the models on digital computers, including effective methods of solving the equations. Due regard for random factors is necessary in estimating general properties of the system including its vitality. In the latter case the problem should be treated by simulation with random variations of some of the system parameters. Mathematical model of power system is clarified then the process of the simulations.

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