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PANEL SESSION ON LONG TERM STABILITY

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1. About definitions

The stability of a power system facing a certain disturbance assumes that after the occurrence of this disturbance a steady state operating point is reached in the vicinity of the predisturbance state.

The classical state of the art in power system analysis classifies the stability in different categories according to the behaviour of the system (see fig. 1). So the concepts of transient stability, small signal or dynamic stability and long term stability are defined. Each concept refers to a typical behaviour of the power system and to typical disturbances, typical time frames.

The classical definition of Long Term Stability (LTS) refers to the behaviour of the power system over a period of time of a few minutes or a few tens of minutes, making the assumption of quasi stationary rotor angle differences between generators.

The assessment of stability relies generally on time domain simulation. Each kind of stability leads to the set up of a mathematical model of the power system centred on the phenomena relevant to the class of stability and simplifying the others.

But, in reality, different kinds of dynamics are intermingled. Also a fast unstable event (for instance, loss of synchronism of a generator) may appear along a slow variation of the state of the system (due to tap changers operation, voltage decrease, ...). As a consequence, the classical long term stability programs based on the simplification of the rotor movements, are not really convenient.

One of the reasons of the development of the multiple concepts of stability has to be found in historical limitation in computation speed and algorithmic performances.

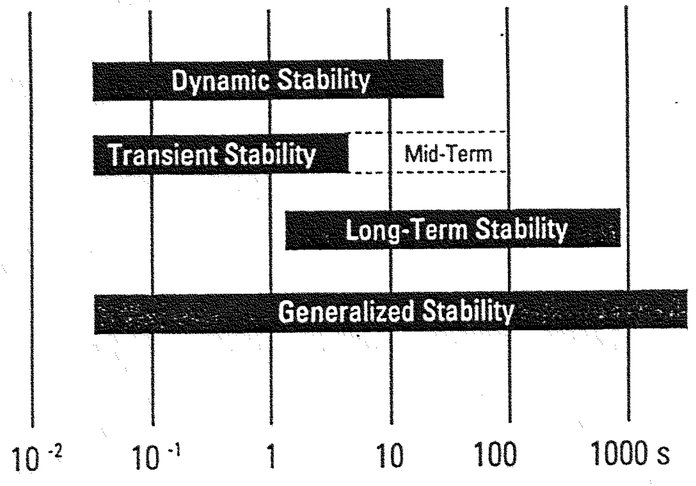

Fig. 1 : Time frame of classes of stability

Recent progress in both fields induces some reasons to unify the different classes of stability.

The more recent concept of mid-term stability consists in extending the time frame of transient stability up to a few minutes, adding automatic tap changers, exciter limiters, ... to the modelling.

The most attractive concept, hereafter called "generalized stability" consists in extending the time frame up to the complete return to equilibrium, whatever the disturbance and possible cascade trippings.

To assess the generalized stability, a very accurate trajectory of the system must be calculated to make sure that any bifurcation, undamped oscillations, ... , have been caught.

2. The generalized stability model

The generalized stability model covers a frequency range from about 10 Hz down to 0.001 Hz. In terms of physical phenomena, it goes from generator rotor transients up to slow thermal phenomena of boilers and centralized controllers. Wave propagation phenomena and harmonics are therefore excluded.

Beside the wide frequency range, extreme operating conditions must be also modelled.

The general characteristics of the model are summarized hereafter :

- **Network** : The classical load flow model is used. Sensitivity of impedances to frequency is included.
- **Generator** : The classical Park's equations must be completed with a good model of saturation.
- **Primary controllers** (excitation, turbine, boilers) : Beyond the main loop, auxiliary and limiting loops must be taken into account.
- **Centralized Controllers** : AGC, centralized voltage control are parts of the model.
- **Transformers** : Models must include automatic tap changers and magnetic saturation.
- **Loads** : The dynamic behaviour, at least as regards induction motors, effect of automatic tap changers of distribution transformers must be taken into account Special large industrial loads may need special modelling. Steady state sensitivity of active and reactive power to voltage and frequency will be modelled.
- **Compensation devices, FACTS** : The static and dynamic characteristics as well as their behaviour when acting on their limits are to be represented.
- **Protective devices** : Overload, loss of synchronism, under or overvoltage, under or overfrequency protections, frequency load shedding, etc... must be modelled accurately.
- **Operator actions** : When time frame becomes long, operators may intervene, creating the needs of interactions on the simulation.

The generalized stability model has the double characteristic of uniqueness and flexibility.

Uniqueness is obvious because it replaces the transient, mid-term and long term stability models.

Flexibility results from the following considerations : when the dynamics of a power system are perfectly known and when the purpose of the simulation is well defined and limited, some simplification of the modelling may happen. On the contrary, when a first analysis demonstrates the key role of one element of the simulation, the model could require some specific enhancements at the level of that element.

3. Mathematical properties of the generalized model and algorithmic solutions

The algebraic differential system representing the generalized model has the following characteristics :

- The size of the system is greater than the one of the transient stability model (more differential equations are needed for generating units and load models). It reaches usually thousands variables and even tens of thousands.
- The system is stiff, having dispersed eigenvalues
- The system is oscillating, having poorly damped eigenvalues.
- The system is strongly non-linear.
- Discontinuities of algebraic variables or of derivatives of differential variables are numerous.

Having in mind the previous characteristics, the algorithmic solution may be defined :

- To merge accuracy and speed of calculation, a variable integration stepsize is necessary.
- To secure numerical stability and a correct simulation of the physical damping, an implicit A-stable method is necessary.
- The solution of the algebraic equations must be simultaneous to the solution of the differential equations. A common practice in transient stability algorithms consists in solving algebraic (network) and differential (generating units) equations alternately. This way of doing is based on the existence of a physical interface separating the two families of equations : the airgap flux of the generators which varies little during an integration step. With variable stepsize, this interface is no more relevant. Moreover, algebraic equations are also used in the generalized model of the units.

Beside a robust integration method, a user defined modelling capability is needed to allow the required flexibility of the modelling (see § 2).

Practical experiences with such algorithm [1] [2] [3] demonstrates that variable stepsize is a mature technology. The stepsize varies usually by a factor of 10 000 or even more during a same run, allowing to calculate post-disturbance equilibrium point rapidly and with a very high accuracy. This property makes the generalized stability model very efficient to compute quasi stationary evolutions, replacing load flow like specialized programs, as used for voltage collapse assessment, for example.

4. Field of application of L.T.S.

Fig. 2 gives a general overview of the use of the generalized model. This figure is self explanatory. Longer term simulations are mainly used for the design of centralized controllers (AGC, centralized voltage control,...); for the study of black-outs (voltage collapse inclusive), for post-mortem studies as well as for the set-up of defence plans and advanced black-start procedures. We note that, beside public networks, large industrial plants with cogeneration represent an important field of application of L.T.S.

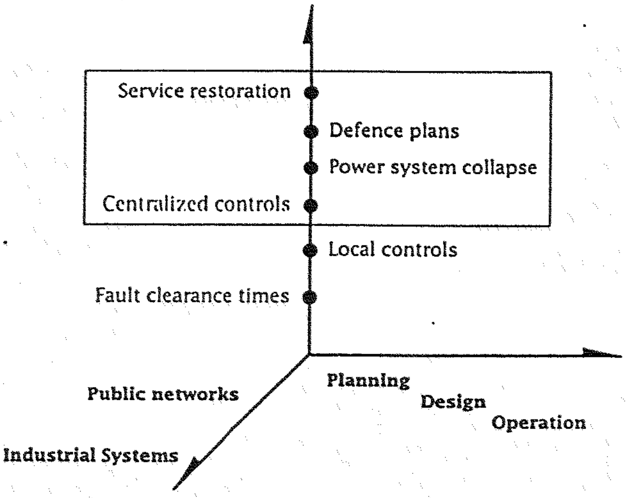

Fig. 2 : Applications of the generalized stability model and of long term stability.

5. Example of LTS study : defence plan against frequency collapse

In the Western European interconnected grid (UCPTE) each country is supposed to have a suitable load shedding scheme to face together a very improbable large loss of generation. Moreover, in case of frequency falling below 49.5 Hz, each country is allowed to open its interconnections.

The islanding of the Belgian system is presently under investigation. Let us imagine the following hypothetical scenario : A major loss of generation in the North of UCPTE provokes (load shedding outside Belgium being disable) a frequency deviation up to 48.5 Hz in 17 s (see fig 3, up). A first local criterion for the opening of the eight tie-lines consists of a frequency threshold (48.5 Hz) and an active power exportation threshold (100 MW), with a time delay of 150 ms. The rotor swings resulting from the first tie-line openings provoke a local frequency oscillation blocking the opening of the last tie-line, resulting in a loss of synchronism of the whole Belgian system against the French one (see fig. 3, down).

Another method for isolating the Belgian system would consist in using the same thresholds, but taking the decision of tripping at a central level. Fig. 4, up shows the behaviour of the mean frequency of the Belgian system in such a case. First, frequency falls around 48.5 Hz, as before. The isolation of the system provokes the recovery of the frequency up to 49.5 Hz. Then, a second frequency drop occurs.

The explanation of this phenomenon has to be found in the boiler control design of some thermal units (see fig. 4, down).

After opening of turbine valves under the control of the speed governor, boiler pressure decreases up to 95 % of nominal value. At that level the governor switches to boiler pressure control mode, provoking the partial reclosing of the turbine valves up to the restoration of steam conditions. Eventually, the boiler control action combined with the dynamic behaviour of the load allow the recovery of the frequency.

In both cases, the static and dynamic characteristics of the load are paramount to define the true behaviour of the load shedding and of the system frequency.

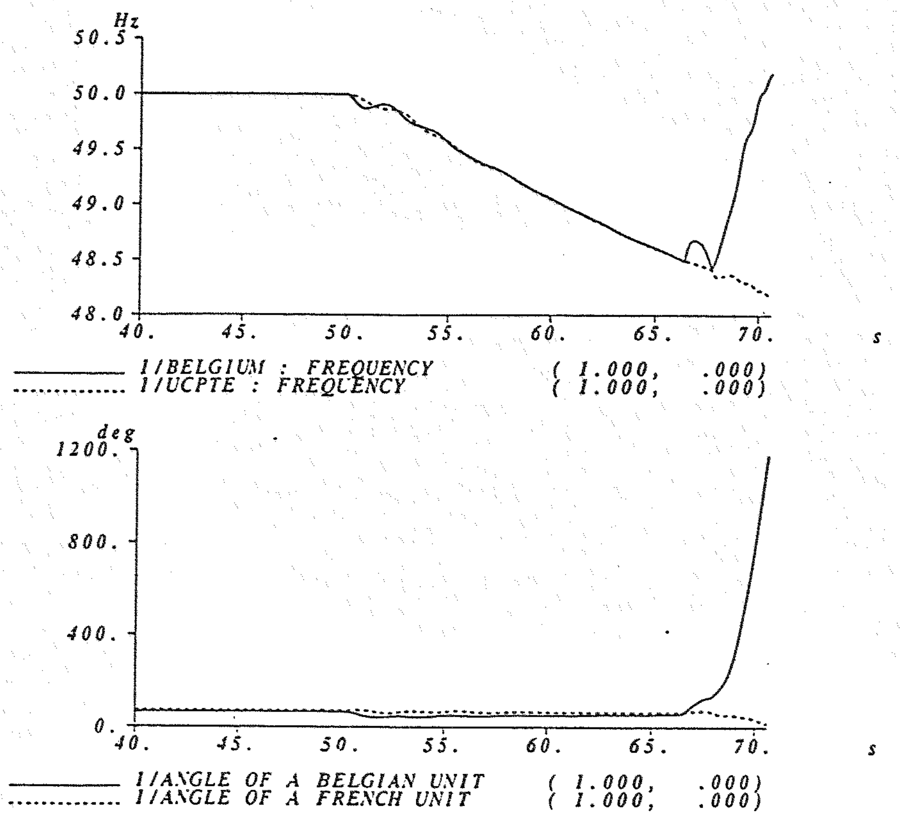

Fig. 3 : Defence plan of the Belgian System : Separation in case of large loss of generation in UCPTE System

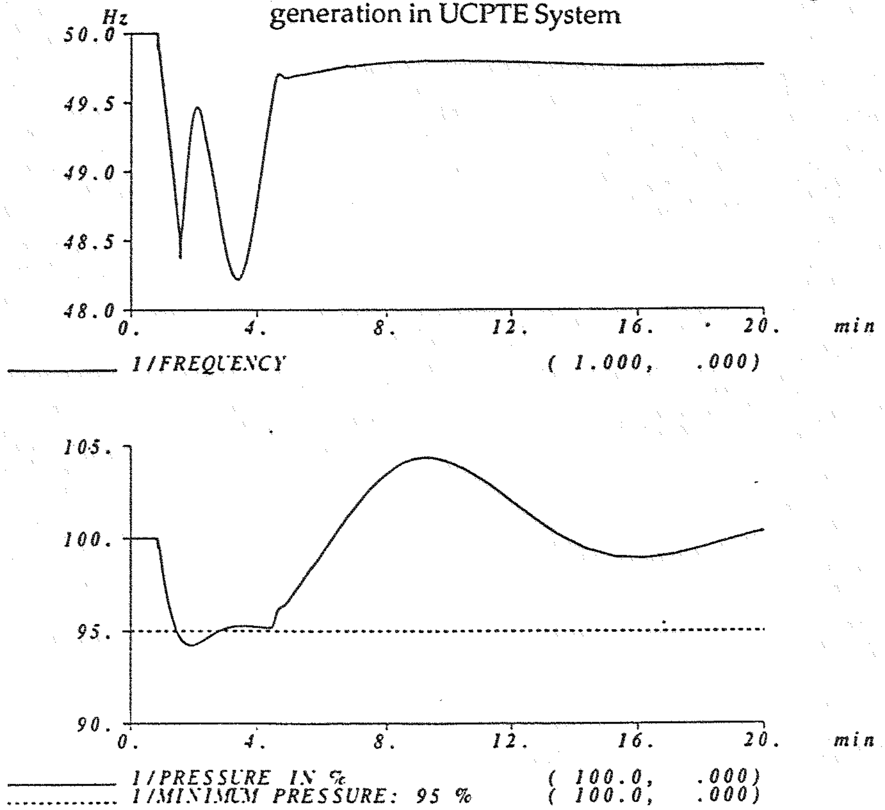

Fig. 4 : Defence plan of the Belgian System : Long Term behaviour of frequency and drum pressure after separation from UCPTE

6. Future trends and industry needs

The rapidly increasing interest of power system engineers for advanced simulations has mainly two origins :

- the new challenge of operating power system nearer to their physical limits;
- the use of new powerful technologies (hardware and software) making high performance simulation easier to implement or eventually possible.

The generalized stability or LTS model allows to run all dynamic simulations of power system for study purpose. It has the great advantages of uniqueness and accuracy. The presently available simulation technology (hardware and software) [3] is utterly efficient.

Thanks to expected increases in computation power and further developments in programming (parallel processing) the field of application of LTS will be extended in the next years to the following areas :

- **On-line dynamic security assessment** (DSA), including voltage collapse. DSA could possibly replace the present static security assessment, to take advantage of the better accuracy of the model, compared to the classical load flow model.
- **Enhanced operator training simulator engine**. The generalized stability model will improve the robustness and the accuracy of the simulation.
- Real time test bed for advanced EMS applications and centralized controls.

7. References

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