STEADY-STATE STABILITY LIMIT IDENTIFICATION FOR LARGE POWER SYSTEMS

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This paper is treating the problem of steady-state stability reserve identification in a power system when realizing off-line simulations. Even in off-line simulation the stability reserve of a power system is not a straight forward analysis. The difficulties appear when trying to solve the stability reserve aspect for a large power system. Present paper is illustrating the steady-state stability limit identification by using eigenvalues, eigenvectors computation. A software application created by the authors under Matlab software tool is used in combination with PSA/Eurostag in order to compute the eigenvalues of the steady-state matrix.

Keywords: steady-state stability, eigenvalue, steady-state matrix analysis.

1. Introduction

This document is focusing on the specific aspects related with the stability reserve on modern power systems.

Modern engine tools used to analyze the behavior of a power system from all points of view, present both advantages and disadvantages. The major advantage of present software tools consists in the ability of modeling very large power systems both in terms of load flow and dynamics. On the other hand one of the greatest disadvantage consists in the need of a huge amount of information that have to be implemented as input data, another big problem being the computational burdens especially in the dynamic simulations. These computational burdens are caused by the large number of differential equations created as a result of having a detailed dynamic model of the analyzed power system which includes all the automatic controllers of the generating units.

The PSA/Eurostag software platform was not a part of above mentioned aspects in the recent history. This software tool is composed of several software packages integrated through a common data model. The computation area is including: load flows, short-circuit, optimal power flow, single line diagram

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representation, security analysis tool. All the dynamic behavior is modeled and analyzed using the Eurostag software tool [1].

With the present release of PSA/Eurostag we are able to linearize any large power system with the scope of having like input data for further analysis the steady-state matrix. Once having the steady-state matrix of the system, eigenvalues may be computed in order to assess the state of a specific operating point: stable or unstable when speaking about steady-state stability.

2. Steady-state matrix analysis

Steady-state matrix analysis is starting from the following relation:

$$\frac{d}{dt}\underline{x}(t) = A * \underline{x}(t) + B * \underline{u}(t) + \Gamma * \underline{p}(t) \tag{1}$$

where A, B, Γ represent the state, control and perturbation matrix and the vectors $\underline{x}(t), \underline{u}(t), \underline{p}(t)$ are the state, control and perturbation vectors.

The state matrix A from equation (1) depends on system parameters and on operation conditions when in the mean time the perturbation matrix Γ and control matrix B depend only on system parameters.

Therefore for certain operation conditions and system parameters, the eigenvalues of the system are obtained by solving the system characteristic equation.

System stability depends on the eigenvalues of the steady-state matrix as follows:

- A real eigenvalue corresponds to a no-oscillations mode. A negative real eigenvalue do represent a stable system and in the mean time a positive real eigenvalue represents an unstable system.
- A pair of complex eigenvalues corresponds to an oscillation mode. The real part of the eigenvalue gives the damping and the imaginary part gives the oscillation frequency. A negative real part of the eigenvalue represents a damped oscillation and a positive real part of the eigenvalue represents an un-damped oscillation.

In order to find out the steady-state stability limit the following methodology was applied [2]:

1. Obtaining an operating point of the analyzed power system
2. Applying a “worsening” procedure by accentuating the power excess/deficit of the analyzed area
3. The new created load flow is analyzed with the PSA/Eurostag software by linearizing the analyzed power system
4. The steady-state matrix is introduced like input data in the software tool

created for eigenvalues computation

5. If no eigenvalue present positive real part the process is continued by turning back to point no. 2.
6. If in the eigenvalues list there is an eigenvalue with positive real part and the defined computation steep is reached, the iterative process is stopped, the last analyzed operating point being identified like the steady-state stability limit.

The PSA/Eurostag platform software is used in order to create the linearized model of the power system. Following the system linearization the input data for the created computation tool is obtained in tabular format with the following characteristics: number of the algebraic variables, number of the differential variables, linearized matrix of the system.

Inside the created computation tool, the needed mathematical equations are implemented in order to obtain the steady-state matrix of the analyzed system by extracting the algebraic equation from the linearized matrix. The mathematic equations used for steady-state matrix identification are :

$$[A_{linearizare}] = \begin{bmatrix} M\,N \\ P\;\;Q \end{bmatrix} \tag{2}$$

$$[A] = [M] - [N]x[Q]^{-1}x[P] \tag{3}$$

where the linearized matrix, $[A_{linearizare}]$, is computed with PSA/Eurostag platform and includes both the algebraic equation and differential equation , and the steady-state matrix $[A]$ contains only the differential equations of the analyzed power system.

3. Algorithm for eigenvalues computation

As been mentioned for steady-state stability assessment in large power systems using PSA/Eurostag software the authors have developed a simple computation tool under Matlab [3]. The goal of this new computation tool is to create the steady-state matrix of analyzed power system and compute the eigenvalues of this matrix, having like input data the linearized power system.

The main steps of the algorithm used for eigenvalues computation in large power system are listed below:

1. Import linear model of the analyzed power system from PSA/Eurostag, Reading the number of variables of the power system (algebraic and differential variables as well as the matrix form of the linear model,

$A_{ini}[nv,nv]$ where nv is the total number of the variables of analyzed power system;

2. Initialize the state matrix of the system;

$$A_{sistem}[i,i] = zeros\,(nv,nv); \tag{4}$$

3. For $i \le nv$

$$A_{sistem}[i,i] = A_{ini}[i,i]; \tag{5}$$

4. Initialize the steady-state matrix of the system,

$$A[j,j] = zeros\,(ndif\,,ndif\,); \tag{6}$$

where $ndif$ is the total number of the differential variables,

5. Create the sub-matrices

$$\begin{aligned} M &= A_{ini}\left(1:ndif\,,1:ndif\,\right);\\ N &= A_{ini}\left(1:ndif\,,ndif\,+1:nv\right);\\ P &= A_{ini}\left(ndif\,+1:nv,ndif\,+1:ndif\,\right);\\ Q &= A_{ini}\left(ndif\,+1:nv,ndif\,+1:nv\right); \end{aligned} \tag{7}$$

6. Create the steady-state matrix

$$A[j,j] = M - N * inv(Q) * P; \tag{8}$$

7. Compute the eigenvalues of the steady-state matrix

4. Case study

The case study analysis was performed on the Romanian power system for a specific constrained area.

The Romanian Power System (RoPS) is in the center of the Southeastern European interconnection and sustains MW transfers between parties situated beyond its geographical borders. A further complication comes from the fact that the network consists of electrical areas interconnected through stability constrained transmission paths. The system operation is quite complex and the dispatchers must meet conflicting requirements in order to maximize the use of the transmission system while avoiding the risk of blackout [4].

One of the stability constrained links is treated in this paper: the *southeastern area* of the Romanian grid. The power exchange between analyzed area and the rest of the RoPS and Bulgarian power system respectively in the initial state (base case load flow) is indicated in Figure 1.

Analyzed area is an area with a power excess for this reason we have identified the maximum amount of power that can be generated inside this area before instability to occur.

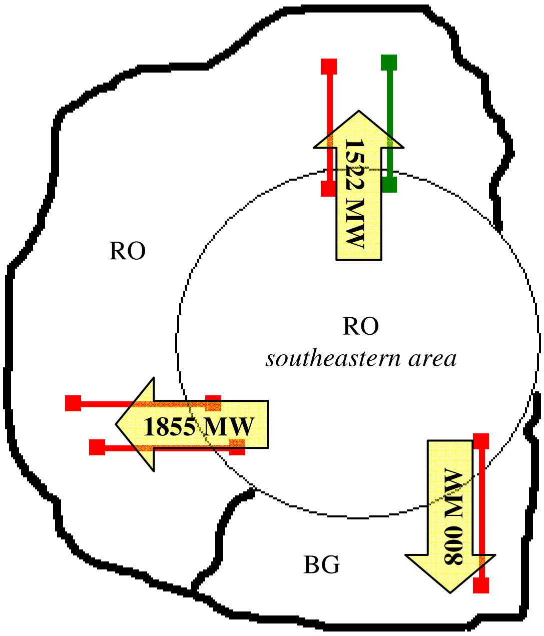

Fig. 1. Base case load flow on *case study*

The case study was implemented on the whole Romanian power system which consisted in: 1097 nodes, 1321 lines, 232 transformers, 679 loads, 15 capacitor banks, and 227 generating units.

Applying the methodology described in section II, we were able to compute successive load flows which were introduced like input data in the computation tool created by using the algorithm described in section III.

The total amount of power excess from analyzed area could be increased up to a surplus of about 3990 MW, value for which instability occurred (Table 1).

Table 1

Steady-state matrix eigenvalues – Case study

Valori proprii critice				
Nr.	$P_{stable\ case}$ = 3937 MW		$P_{unstable\ case}$ = 3985 MW	
	real	imaginar	real	imaginar
1	-5.48E-03	6.09E-15	1.25E-11	0.00E+00
2	-5.48E-03	-6.09E-15	-5.48E-03	0.00E+00

From the total 1306 eigenvalues in Table 1 only first two smallest eigenvalues are presented.

For the analyzed constrained area we concluded as having a 3937 MW limit power excess before steady-state instability might occur.

5. Conclusions

Present paper is illustrating the ability to assess the steady-state stability in large power systems using both PSA/Eurostag software platform and a new computation tool created by the authors under Matlab.

A case study on the Romanian electrical grid was also performed by identifying the maximum power transfer from the southeastern area to the rest of the analyzed power system, loading limit beyond that the instability occurs.

The proposed methodology might be successfully applied on any large electrical network. The most interesting aspect of all is that proposed approach is giving the stability reserve of a power system by analyzing a very detailed model of the electrical network.

R E F E R E N C E S

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