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Creation of Stability Index for Micro Grids

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Abstract This paper is qualified for creation of a new stability index for micro grids (MG) in cooperation with the power system (PS), which characterizes the dynamic security of MG well. Primary objective of this paper is to examine the effect of continuously increasing integration of intelligent energy distribution networks, concerning the stability of the PS. The model used for simulating the MG and the calculation method of the new stability index are published in this paper. Simulation results of model network are described, conclusions are drawn and evaluated.

Keywords
Stability index, micro grid (MG), power system (PS), power balance, time-domain simulations.

1. Introduction

The development history of PS proceeded through similar phases everywhere: the initial local supply was followed by transfers of shorter distance and finally national interconnected networks came into operation. These networks were connected for the sake of mutual technical help and nowadays the networks are also used for great commercial transports, covering whole Europe. This global PS definitely has many advantages, but nowadays its disadvantages come increasingly into foreground. As a consequence of the high loading of system elements, the reliability of supply is decreasing, provided by some recently recorded cases.
Network structures are needed to be established, the direction of which are more favorable and designable. They simplify the system – regarding system regulation – are able for island operation and in some cases they can join to the PS. The MG can be a solution for the above questions. On the other hand for the examination of these kinds of micro networks it is essential to create a suitable MG model.

2. Calculation method

Two different methods were compared. The first one is the so called TSI method. The transient stability index is used to get information about the system stability.
The basic idea is that calculation of angular accelerations of the machine units at the instant fault can be used to get useful information about the system. An index can be formulated from these accelerations that will give information about the disturbance on the whole system. The calculation method is described in the following points:

• Assuming that a 3Φ-fault occurs at the node of i-th machine unit at t=0. Calculate the angular accelerations of the examined machine units (relative to a reference machine – noted by index n), and find the maximum of these values:

$$\varepsilon_i^r = \max_{k=1..n-1} \left| \varepsilon_k - \varepsilon_n \right|$$

• Calculate the average angular acceleration of the whole system:

$$\bar{\varepsilon} = \frac{1}{n} * \sum_{j=1}^{n} \varepsilon_j^r$$

• Calculate the difference of each acceleration from this average:

$$\Delta_i = \left|\varepsilon_i^r - \overline{\varepsilon}\right|$$

• After calculating Δ_i for the case of the fault occurring at all examined machines, TSI can be defined as:

$$TSI = \max_{i=1..n} \Delta_i$$

In order to become familiar with the characteristic values, behavior and meaning of the obtained TSI values, the results with time-domain simulation of the same cases need to be compared. One of the most characteristic results of these simulations is the critical clearing time, i.e. the maximal duration of the fault before clearing, after which all machine units can return to synchronous operation in a new equilibrium. It is possible to get reliable information based on the value of Transient Stability Index. The correspondence between TSI and CCT values is strictly monotonous, so critical clearing times can be unambiguously estimated.

Although this method is useful a new one has been created, which is sharper and the calculation requirements are less.

This new method is the Δt method. The aim of calculation method is to get the short circuit currents in the system at optional location of the short circuit. The system parameters are known. In a short circuit case on a bus there is a short circuit current. This current comes from the generator connected to the failure bus, and from the whole remaining system. The current deriving from the generator is easy to calculate. If the short circuit current can be obtained on the bus, we can calculate the remaining systems current. From these parameters it is easy to obtain the so called remaining systems impedance and complex voltage level. The first step is the short circuit current.
The calculated 3-phase sc.-s are supposed to be impedance-less. The voltage levels of the buses are in the simulator software (this case the Power World simulator). This program is able to generate an admittance matrix directly in MATLAB form, and the voltages are contained as well.
The necessary equations to calculate the sc. currents:

$$I_{zh} = \frac{V_h^0}{Z_{hh}}$$

$$V_j = V_j^0 - Z_{hj} I_{zh}$$

$$I_{ji} = (V_j - V_i) y_{ji} + V_j \frac{y_{ji}^{'}}{2}$$

Following these calculations, the branch currents and the bus voltages during the fault are known.
Only one more step is necessary to get the stability index, using the equal area method.

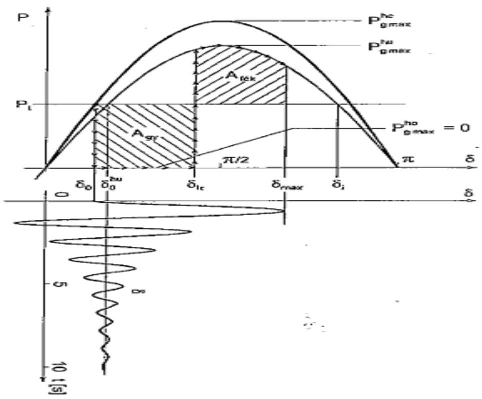

Figure 2.1.: the equal area method

$$P_m * \Delta\delta_{\max} = \int_{\delta_{le}}^{\delta_i} (P_{\max} * \sin\delta - P_m) d\delta$$

$$P_m * \Delta\delta_{\max} = P_{\max} * (\cos\delta_{le} - \cos\delta_i) - P_m * (\delta_i - \delta_{le})$$

$$\Delta\delta \equiv \delta_{le} - \delta_0$$

$$P_m \Delta\delta = P_{\max}(\cos(\delta_0 + \Delta\delta) - \cos\delta_i) - P_m(\delta_i - \delta_0 - \Delta\delta)$$

$$0 = P_{\max}(\cos(\delta_0 + \Delta\delta) - \cos\delta_i) - P_m(\delta_i - \delta_0)$$

$$\cos(\delta_0 + \Delta\delta) = \cos\delta_i + \frac{P_m}{P_{\max}}(\delta_i - \delta_0)$$

$$\delta_0 + \Delta\delta = \arccos(\cos\delta_i + \frac{P_m}{P_{\max}}(\delta_i - \delta_0))$$

$$\Delta\delta = \arccos(\cos\delta_i + \frac{P_m}{P_{\max}}(\delta_i - \delta_0)) - \delta_0$$

From this calculation the angle changing caused by the failure could be got. From this parameter the angle acceleration should be calculated, this is the ε'.

$$M_i = \frac{H_i \cdot S_{ni}}{\pi \cdot f_n} \rightarrow \varepsilon = \frac{P_s}{M} \rightarrow \Delta t = \sqrt{\frac{2 \cdot \Delta\delta}{\varepsilon}}$$

This method is similar to the TSI method, however the way of the calculation is a bit different. The Δt parameter was used, to compare the angle accelerations to the time, instead of critical clearing time.

3. Model description, simulations

For examination purposes a network analyzer software package – developed by the Department of Electric Power Engineering, TU Budapest – was used for the TSI calculations. With the help of the program steady states of networks (load-flow calculations), effects of several faults and breaker operations during transients can be analyzed. In addition to the steady-state analysis, dynamic simulations were also calculated. The program is able to handle two synchronous systems operating with different frequency. The Δt method was calculated by Power World Power Systems Analysis Software for the steady-state simulations. Power World Simulator is an interactive power system simulation package designed to simulate high voltage power system operation on a time frame ranging from several minutes to several days. The software contains a highly effective power flow analysis package, capable for solving systems of up to 100 000 buses effectively.
Power World offers several optional add-ons to extend analyzing capabilities of the simulator. The model topology is shown in Fig. 2., which was created by using Power World SAS. The network model consists of:

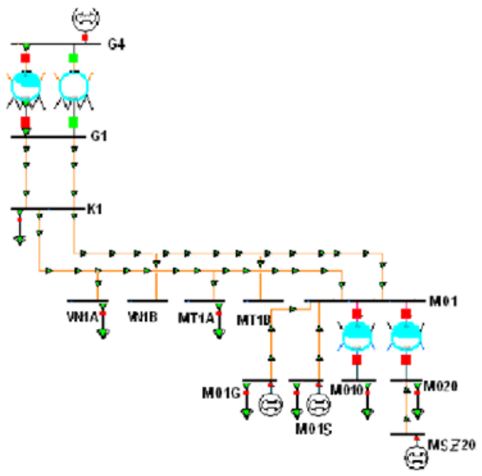

Fig. 2. The topology of the model network

- high- and middle voltage lines
- and buses (400-120-20 and 10-kV)
- transformers
- lines, parallel-lines
- generators and loads.

The sources may be power and/or voltage controlled. In the model there are:

- two wind power parks connected to MO1S and MSZ20 buses,
- three 5 MW gas turbines (connected to the MO1G bus)
- and a large machine (connected to the G4 bus) as a system slack bus in case of parallel operation with large network.

During island operation, the gas turbines are the system slack. In the two wind parks 25 x 2 MW wind turbines are in operation. The loads are frequency and voltage dependent.
Different system states were calculated. The loads were changed in case of cooperated operation and in island operation as well.
The island operation was established with a switch on MT1A-VN1A and MT1B-VN1B lines, and this way the two system frequencies were developed. The following examination consisted of several steps: the network operated as an island i.e. the MO1 bus and geographically close loads and sources form an island. The feasibility of island operation was examined. Different operation situations and faults were simulated; size of voltage change was examined.
In cooperated and island operation the power was in- and decreased.
From the results, it can be concluded that in some cases TSI provided relevant and valuable information on the dynamic security of the MG system; while in other cases, the Δt method has the same or even better results.

	Cooperated operation		
	MO1G	MO1S	MSZ20 #3phsc
M	0,557	1,751	0,700
Ps[MW]	8,000	38,440	7,980
dP-HTSW	0,660	1,810	8,040
dP-Matlab	1,120	1,890	8,040
ε-HTSW	1,185	1,034	11,481
ε'-Matlab	2,011	1,080	11,481
CCT	0,570		
Δt[sec]	0,492		

Table 3.1.: calculation results in coop-op., the fault is at MSZ20 machine terminal

	Island operation		
	MO1G	MO1S	MSZ20 #3phsc
M	0,557	1,751	0,700
Ps[MW]	8,600	38,000	7,980
dP-HTSW	3,360	4,670	7,980
dP-Matlab	2,630	1,290	7,980
ε-HTSW	6,032	2,668	11,395
ε'-Matlab	4,721	0,737	11,395
CCT	0,470		
Δt[sec]	0,542		

Table 3.2.: calculation results in island-op., the fault is at MSZ20 machine terminal

4. Results of the simulations

Comparing the two characteristics, it is easy to recognize, that the Δt method provides accurate results.
The Δt simulation calculations suit better at the expected characteristic, than the TSI method results.
The accelerations in the two methods are very similar, 0.97 correlation was calculated. The critical clearing times however were more different.

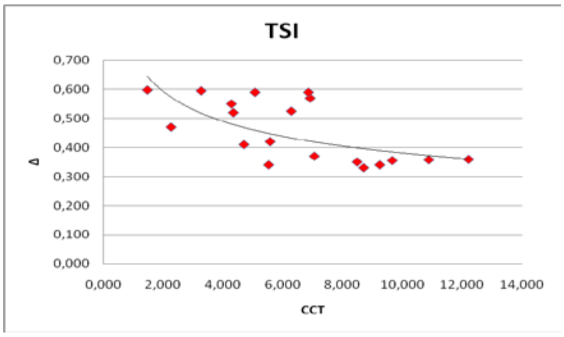

Figure 4.1.: the characteristic by the TSI method

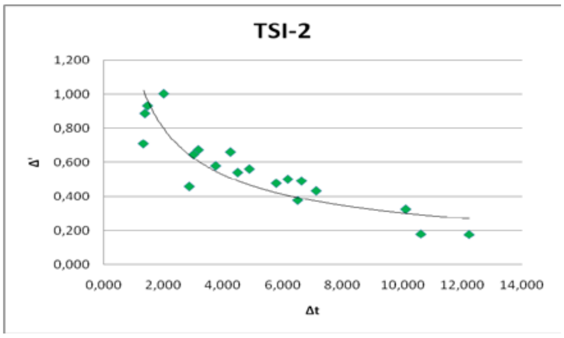

Figure 4.2.: the characteristic by the Δt method

5. Conclusion

The TSI-2 characteristic shows a clearly monotonous correlation between Δt values and critical clearing time.
It is possible to get information on dynamic security of particular system states, based on the value of examined index, rather than by using other methods.
A complete MATLAB program was created. With the help of this software, it is easy to get the TSI-2 characteristics. The Power World simulator can send the admittance matrix; afterwards the calculation is automatic.
The stability indices were originally created to reduce number of calculations by substituting complicated, time-domain analyses. Nowadays this aim has lost its importance as a consequence of available computational capacity growth. However, stability indices can be very useful to monitor stability state of the system on-line by automatic calculations.
In case of large system the number of calculations can be very high. The calculation of time-domain analysis is faster nowadays, but it takes plenty of time. In this cases could be useful the new method as well.

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