A New Calculation Method of Total Transmission Capacity (TTC) Taking into Account Various Kinds of Stability

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Abstract – It is important to know how much power can be transferred from a point to a point or from a group of generators to a local point in a power system at this moment and in the future from the viewpoint of system operation and planning. Also in deregulated circumstances of power system in the world, it has already become possible for the third parties such as IPPs and customers to have access to transmission network for wheeling. Under the above conditions it becomes more and more important to calculate *Total Transmission Capacity* (TTC) or *Available Transmission Capacity* (ATC) as precisely and efficiently as possible considering not only (N-1) rule based thermal line flow limit but also various kinds of stability such as transient stability, small-signal stability and voltage stability. In this paper, a new efficient method for evaluating TTC based on a linear optimization problem using sensitivities of the stability indices with respect to the wheeling power is proposed. In the proposed algorithm, a simplified energy function and eigenvalues are used as the transient stability and the small-signal stability indices respectively. The voltage stability is also considered. It is made clear from the simulation results for a model power system that various kinds of TTC such as a point-to-point TTC and multiple generators-to-a specific load TTC taken into account the stabilities can be calculated efficiently.

Keywords: TTC, Small signal stability, Transient stability, Voltage stability, Optimization, Overload, N-1 security rule

1. INTRODUCTION

In deregulated environments of power markets, it becomes more and more important to know how much power can be transferred from a point to a point or from a group of generators to a local point keeping security and reliability of power supply at a high level at this moment and in the future [1]. For this purpose, a new efficient calculation method of Total Transmission Capacity or Total Transfer Capability (TTC) is expected to be developed and to be used for on-line power system operation and power market transaction.

In particular, not only thermal line flow limit based on (N-1) security rule but also various kinds of stability such as voltage stability, small signal stability and transient stability have to be taken into account for evaluating TTC in Japanese power systems different from USA systems because the power systems in Japan have some stability problems.

There exist some definitions of TTC as below [2]:
(i) From a specified generator bus to a specified load bus
(ii) From multiple generator buses to a specified load bus
(iii) From a specified generator bus to multiple load buses
(iv) From multiple generator buses to multiple load buses

In this paper a new efficient method for evaluating TTC based on a linear optimization problem using sensitivities of the stability indices with respect to the wheeling power is proposed, where a simplified energy function and eigenvalues are used as the transient stability and the small signal stability indices respectively. The voltage stability is also checked by existence of the physically feasible load flow solutions. Numerical examples are given for TTC of (i) and (ii) mentioned above in a model power system to show effectiveness of the proposed method.

2. CONSTRAINTS OF TTC CALCULATION

In this paper, we consider voltage stability, small signal stability, transient stability and thermal power flow limit based on N-1 security rule as constraints of TTC calculation. N-1 security rule means that even if one of the facilities such as transmission lines, transformers, generators etc. is not available, the stabilities are maintained and the load flows on transmission lines are kept within the thermal power flow limit. The stability constraints are indispensable for evaluating TTC, in particular, in Japan. The stabilities except for voltage stability are handled by using sensitivities of the indices with respect to the wheeling power, where the sensitivities are obtained analytically.

A. Voltage Stability

When a load flow calculation for specified real and reactive powers or specified voltage magnitudes gives a physically feasible solution, the power system is considered to be stable from the steady-state voltage stability viewpoint as shown in figure 1. As the conventional load flow calculation method using Newton-Raphson method may not identify the existence of the solution near the load flow critical point under the heavily loaded condition, we use the following method developed before by the author [3]. In this method, the calculation is carried out by using Newton-Raphson method in the complex-number domain extended from real-number domain. It gives us a solution of real-number voltage magnitude and phase angle if the voltage solution exists physically. If not, it gives us a solution of complex-number voltage magnitude and phase angle. Please refer to [3] for the detailed algorithm.

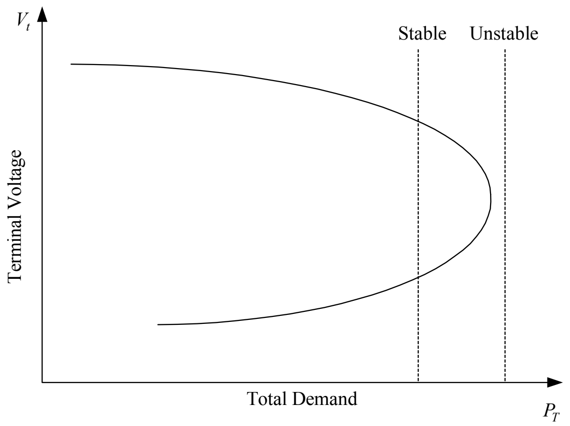

Figure 1: Voltage Stability

B. Small-Signal Stability

The following state equations are obtained by linearizing nonlinear differential equations and algebraic equations of a power system around an operating point.

$$A_G \dot{\underline{x}}_g + B_G \Delta\underline{V} = C_G \underline{x}_g \tag{1}$$

$$Y\Delta\underline{V} = D_G \underline{x}_g \tag{2}$$

$\underline{x}_g$: a vector of state variables of generators

$\Delta\underline{V}$: a vector of deviations of generator terminal voltages

By eliminating $\Delta\underline{V}$ from equations (1) and (2):

$$\dot{\underline{x}}_g = A\underline{x}_g \tag{3}$$

$$A \equiv A_G^{-1}(C_G - B_G Y^{-1} D_G) \tag{4}$$

Now, if all of the real parts of eigenvalues of matrix A are less than σ_D (≤ 0), the system damping is suppressed well and the power system is considered to be stable from the viewpoint of small signal stability. In the optimization process of evaluating TTC, we consider the constraints in association with the eigenvalues so that all of the real parts of the eigenvalues are less than σ_D as shown in figure 2. Eigenvalue sensitivities with respect to active power flows at generator and load buses are used for estimating the shifting values of the real parts of the eigenvalues due to the change of the wheeling power [4].

The eigenvalue sensitivity is calculated analytically by using the following equation:

$$\frac{d\lambda_j}{dP_{flow}} = \underline{v}_j^T \frac{dA}{dP_{flow}} \underline{u}_j \tag{5}$$

$$\underline{v}_j^T \underline{u}_j = 1$$

λ_j : an eigenvalue of matrix A

$\underline{u}_j$: right eigenvector in association with λ_j

$\underline{v}_j$: left eigenvector in association with λ_j

P_{flow} : wheeling active power flow

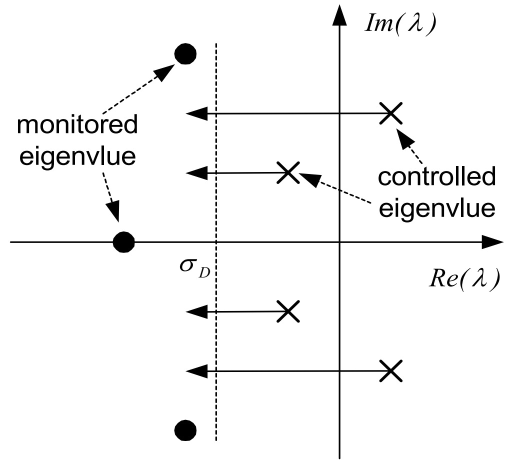

Figure 2: Eigenvalue shift

Because matrix A is a function of steady-state values x_0 and V_0 of state variable $\underline{x}$ and terminal voltage $\underline{V}$ of generators, a sensitivity of matrix A with respect to parameter ξ such as x_0 and V_0 is as follows:

$$\frac{\partial A}{\partial \xi} = A_G^{-1}\Big(\frac{\partial C_G}{\partial \xi} - \frac{\partial B_G}{\partial \xi} Y^{-1} D_G - B_G Y^{-1} \frac{\partial D_G}{\partial \xi} - \frac{\partial A_G}{\partial \xi} A + B_G Y^{-1} \frac{\partial Y}{\partial \xi} Y^{-1} D_G\Big) \tag{6}$$

Using equation (6) we can obtain the following derivative of A with respect to the wheeling active power:

$$\frac{dA}{dP_{flow}} = \frac{\partial A}{\partial x_0}\frac{\partial x_0}{\partial \underline{V_0}}\frac{\partial \underline{V_0}}{\partial P_{flow}} + \frac{\partial A}{\partial x_0}\frac{\partial x_0}{\partial P_{flow}} + \frac{\partial A}{\partial \underline{V_0}}\frac{\partial \underline{V_0}}{\partial P_{flow}} + \frac{\partial A}{\partial P_{flow}} \tag{7}$$

C. Transient Stability

Generally, there exist two ways to evaluate transient stability. One is to solve nonlinear differential equations by digital time simulation. The other is to use an energy function or Lyapunov function. As is known well, the former method can check the transient stability strictly but spends a lot of computing time. Since the aim of our work is to conduct the TTC calculation as fast as possible, we adopt an energy function method in this paper.

Here, an energy function in multi-machine power system is described as:

$$V = V_K(\underline{\omega}) + V_P(\underline{\delta}) \tag{8}$$

The first term of the right hand side of equation (8) represents a kind of kinetic energy of generators and the second term represents a kind of potential energy of transmission network. Since it is assumed that fault duration time is short enough, the change of phase angle during the fault is considered to be almost small and the change of V_P is small compared with that of V_K. Therefore, we consider only kinetic energy V_K here.

Now, based on synchronous equilibrium criterion, we use the following equation as a kinetic energy function:

$$V_K(\omega_i) = \sum_{i=1}^{n} \frac{1}{2} M_i (\omega_i - \omega_0)^2 \tag{9}$$

M_i : inertia of generator i
ω_0 : angular velocity of center of inertia

Since electric output of each generator is considered to be almost constant during the short fault time, equations (10) and (11) are obtained.

$$\omega_i^f = \omega_i(0) + \alpha_i t_f \tag{10}$$

$$\alpha_i = (P_{mi} - P_{ei}^{post}) / M_i \tag{11}$$

α : acceleration during fault
t_f : fault duration time
P_{mi} : mechanical input of generator i
P_{ei}^{post} : electrical output of generator i immediately after fault

Substituting equations (10) and (11) to equation (9), the value of V_K at the fault clearing time is obtained as below:

$$V_K(\omega_i^f) \approx \frac{1}{2} \sum_{i=1}^{n} \frac{(P_{mi} - P_{ei}^{post})^2}{M_i} t_f^2 - \frac{1}{2M_T} \left[\sum_{i=1}^{n} (P_{mi} - P_{ei}^{post}) \right]^2 t_f^2 \tag{12}$$

$$M_T = \sum_{i=1}^{n} M_i$$

It is reported in reference [5] that the value of V_K divided by the total load demand P_T, which is denoted by VEP in this paper, is a good index of the transient stability, in particular, the first swing stepping out. The threshold value of the VEP corresponding to the transient stability limit depends on kinds and locations of faults but is almost constant for the change of load flow condition. Therefore, the threshold value can be found for each fault on the off-line basis by solving the nonlinear differential equations by using a digital time simulation method and can be used as the constraints of the optimization problem for calculating TTC.

In this problem, in order to estimate the shifting value of VEP due to the change of the wheeling power, we need the following sensitivities S of VEP with respect to active power P_L of load, mechanical inputs P_m of generators and electrical outputs P_e^{post} of generators immediately after fault.

$$\Delta VEP = S_L \Delta P_L + \sum_{i=1, i \neq (slack=j)}^{n} S_{mi} \Delta P_{mi} + S_{mj} \Delta P_{slack} + \sum_{i=1}^{n} S_{ei}^{post} \Delta P_{ei}^{post} \tag{13}$$

$$S_L = -\frac{VEP}{P_T}$$

$$S_{mi} = \frac{(P_{mi} - P_{ei}^{post})}{M_i P_T} t_f^2 - \frac{t_f^2}{M_T P_T} \sum (P_{mi} - P_{ei}^{post})$$

$$S_{ei}^{post} = -\frac{(P_{mi} - P_{ei}^{post})}{M_i P_T} t_f^2 + \frac{t_f^2}{M_T P_T} \sum (P_{mi} - P_{ei}^{post}) \tag{14}$$

As the control variables of this TTC calculation are active powers P_m of generators and those P_L of loads, it is necessary to obtain sensitivities of the electrical output P_e^{post} of generators immediately after fault and the active power P_{slack} from a slack generator with respect to them in the following way:

$$\Delta P_{slack} = \frac{\partial P_{slack}}{\partial \underline{V_0}} \frac{\partial \underline{V_0}}{\partial P_{flow}} \Delta P_{flow} \tag{15}$$

$$\Delta \underline{P}_e^{post} = \frac{\partial \underline{P}_e^{post}}{\partial \underline{x_0}} \frac{\partial \underline{x_0}}{\partial \underline{V_0}} \frac{\partial \underline{V_0}}{\partial P_{flow}} \Delta P_{flow} \tag{16}$$

D. Thermal Line Flow Limit

Thermal line flow limits based on (N-1) rule are the constraints concerning overload on transmission lines before and after contingencies. To avoid much computing time of load flow calculation by AC method, DC flow method is used in this paper. In general, DC flow circuit equations are formulated as:

$$C\underline{f} = \underline{g} \tag{17}$$

$$C^T \underline{v} = \underline{e} - Z\underline{f} \tag{18}$$

C: node-branch connection matrix
Z: impedance matrix
$\underline{f}$: branch current vector
$\underline{g}$: injected node current vector
$\underline{v}$: node voltage vector
$\underline{e}$: voltage source vector between branches

"$\underline{f}$", "$\underline{g}$", "$\underline{v}$" and "$\underline{e}$" denote real power flow of transmission line, real power of generator or load, phase angle of node voltage and phase shift in DC flow method respectively.

Here, we neglect phase shifter and the following equations are defined:

$$\underline{v}' = -(C' Z^{-1} C'^{T})^{-1} \underline{g}' \qquad (19)$$

$$\underline{f} = Z^{-1} C'^{T} (C' Z^{-1} C'^{T})^{-1} \underline{g}' \qquad (20)$$

$\underline{v}'$, C' and $\underline{g}'$ are formed by removing the element concerning slack node from $\underline{v}$, C and $\underline{g}$ respectively. From equation (20), we obtain

$$\Delta \underline{f} = Z^{-1} C'^{T} (C' Z^{-1} C'^{T})^{-1} \Delta \underline{g}' \qquad (21)$$

In DC flow method the line flow change is approximated to be proportional to the real power change of generator or load by equation (21).

3. ALGORITHM OF TTC CALCULATION

A. TTC from a Point to a Point

Figure 3 shows a flowchart of calculation of TTC from a point to a point. Here, we consider TTC from a slack generator bus to a load bus. If we consider TTC from a non-slack bus, we will assume that non-slack bus to be a new slack generator bus and recalculate load flow calculation based on new slack generator bus. The active power of a slack generator increases by incremental transmission loss. The following points are noted in this algorithm:

- ΔVEP, $\Delta\lambda$ and Δf in the optimization problem are expressed as products of their sensitivities and ΔP_L as described in section 2. The load demand P_L at a given node is only a control variable here.
- Since it is necessary to reduce the number of the iteration for calculating TTC fast, the upper bound of ΔP_L is not considered at the initial state and when the constraints are violated, the upper bound ΔP_L^{max} of ΔP_L is considered.
- ΔP_L is maximized in each iteration and added into P_L until ΔP_L is small enough. The last P_L is a maximum load that refers to maximum power transfer.
- The validity of the constraints is checked after the optimization.

B. TTC from Multiple Generators to a Point

In this section, the active powers of multiple generators P_{m_i} are also treated as control variables. The optimization problem shown in figure 3 is formulated as follows:

max ΔP_L

Subject to

(Transient stability)

$$VEP + \sum S'_{mi} \Delta P_{mi} + S'_L \Delta P_L + S'_{m,slack} \Delta P_{slack} \le VEP^{max} \quad (22)$$

(Small-signal stability)

$$\lambda + \sum \frac{d\lambda}{dP_{mi}} \Delta P_{mi} + \frac{d\lambda}{dP_L} \Delta P_L + \frac{d\lambda}{dP_{slack}} \Delta P_{slack} \le \lambda^{max} \quad (23)$$

(Slack generator output)

$$\Delta P_{slack} = \sum \frac{dP_{slack}}{dP_{mi}} \Delta P_{mi} + \frac{dP_{slack}}{dP_L} \Delta P_L \qquad (24)$$

(Thermal line flow limits before or after contingencies)

$$-f^{max} \le f + \sum S_{mi,flow} \Delta P_{mi} + S_{L,flow} \Delta P_L \le f^{max} \quad (25)$$

(Limits of generator outputs)

$$P_{mi}^{min} \le P_{mi} + \Delta P_{mi} \le P_{mi}^{max} \qquad (26)$$

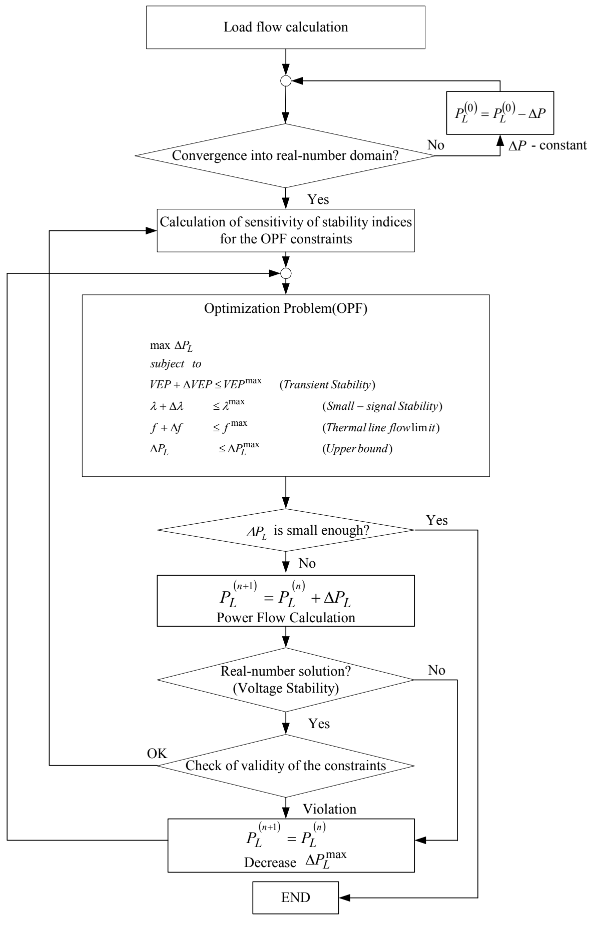

Figure 3: Flowchart for point-to-point TTC calculation

4. NUMERICAL EXAMPLES

Figure 4 shows a model system used in this paper. [6] (In figure 4, "( )" denotes branch number) Constants of generators which are different from those shown in reference [6] are used as shown in table 1.

Analytical conditions are described below:

The line flow limit of transformer is 10 [p.u.], and that of transmission line is 5 [p.u.] per one circuit. As for (N-1) rule, we consider that one circuit of multiple circuit line which is expressed as multiple straight lines in figure 4 is opened. The critical value of eigenvalue σ_D is -8×10^{-4} . 3LGO with the fault duration time of 70 ms at only bus 36 is considered as a contingency of the transient stability and low voltage constraints are not considered in these examples for simplicity. A threshold value of VEP is 1.0×10^{-2} . Computer of JU1/200 (CPU: Ultra SPARC 200MHz) is used in this study. Here, the sparsity techniques or other softwares for speeding up the computation are not adopted, thus the calculation time is quite high. The development of this computation is a future work.

A. TTC from a Point to a Point

TTC from generator 3 to a specified load bus is shown in table 1 with violated constraints, the iteration number and calculation time, where “iteration number” means how often the optimization problem is solved. It is easy to solve the optimization problem because of only one control variable here. “(N-1) rule (a, b)” in the table means that branch “b” is overloaded when branch “a” is opened.

It can be seen from table 2, for examples, that TTC from generator 3 to node 38 is 2.04 [p.u.], which is limited by the overload of line 15 due to the one-circuit open fault of double-circuit line 12, and that the maximum TTC from generator 3 is that to the nearest node 44, which is limited not by the line overload but by the small-signal stability.

B. TTC from Multiple Generators to a Point

Compared with point-to-point TTC in the previous section, much power can be transferred by coordination of multiple generator outputs. Now we assign generator G1-G3, G4-G6, G7-G10 into group 1, group 2 and group 3 respectively, and consider TTC from each group to a specified load within the limits of generator outputs shown in table 3. The optimization problem is solved by simplex method. In the optimization problem, the upper bound of generator incremental output ΔP_{mi} is set to be 1.0, 0.8, 0.6 and later 0.2 [p.u.] according to the increasing number of iteration. The calculation is finished when the absolute value of ΔP_{mi} is less than 0.01.

(i) TTC from Group 1

In this case, the control variables are P_{m1}, P_{m2} and P_L because G3 is a slack generator. Numerical results are shown in table 4. It can be seen that compared with point-to-point TTC, in cases where TTC is limited by small-signal stability, TTC little increases even if the generator outputs are coordinated. It is confirmed by the fact that sensitivities of eigenvalues with respect to the generator outputs are smaller than those with respect to the load demand P_L. It is also seen that the wheeling power is limited by at most two kinds of constraints.

(ii) TTC from Group 2

When we consider TTC from multiple generators not including a slack generator, how a slack generator should be handled is a problem. In this case, the following constraint is added to the optimization problem shown in section 3.B:

$$\Delta P_{slack} = \sum \frac{dP_{slack}}{dP_{mi}} \Delta P_{mi} + \frac{dP_{slack}}{dP_L} \Delta P_L = 0 \quad (27)$$

The above equation (27) means that the incremental transmission loss is assigned to the generator in group 2. The control variables are P_{m4}, P_{m5}, P_{m6} and P_L. Numerical results are shown in table 5. It can be seen from the table that the output power from slack generator 3 is not changed and that the wheeling power is limited by at most three kinds of constraints.

(iii) TTC from Group 3

Here, TTC is calculated in the same way as TTC from group 2. The control variables are P_{m7}, P_{m8}, P_{m9}, P_{m10} and P_L. Numerical results are shown in table 6, from which it can be seen that a lot of TTC are limited by both transient stability due to the fault at bus 36 and small signal stability.

Tables 4, 5 and 6 show that the calculation time increases as the iteration number increases.

C. Discussion

In the numerical examples, there is only one contingency has been considered, the selected case is a severe condition that highly affects TTC calculation, however, it seems not enough to conclude whether it is useful. Other contingencies will be treated in the future work. In this approach, the stabilities except for voltage stability are handled by using sensitivities of the indices, but voltage stability is tested by load flow convergence. There is a recent work provide an effective and fast formula to evaluate the sensitivity for voltage stability [7], it seems efficient to apply such a formula to this approach.

5. CONCLUSION

In this paper, a new efficient method has been proposed for evaluating TTC as fast as possible and has been applied to a model system to show the effectiveness. As a result, it has been made clear that TTC can be calculated efficiently by using the proposed method even if various kind of stability are taken into account and that the method can show the factors by which the wheeling power is limited.

At first, TTC from a slack generator to a specified load bus has been calculated easily in the sense that the incremental transmission loss can be assigned to the slack generator. Then, in case of TTC from a group of generators where a slack generator is not included, it has been made possible that the incremental transmission loss is assigned not to the slack generator but to the generator group by using the sensitivity of output power of the slack generator with respect to the wheeling power.

In the future work, not one but several contingencies have to be taken into account for the transient stability and the bus voltage profile also has to be checked. In addition, relation between TTC and installation and control of FACTS devices such as TCSC and UPFC will be studied.

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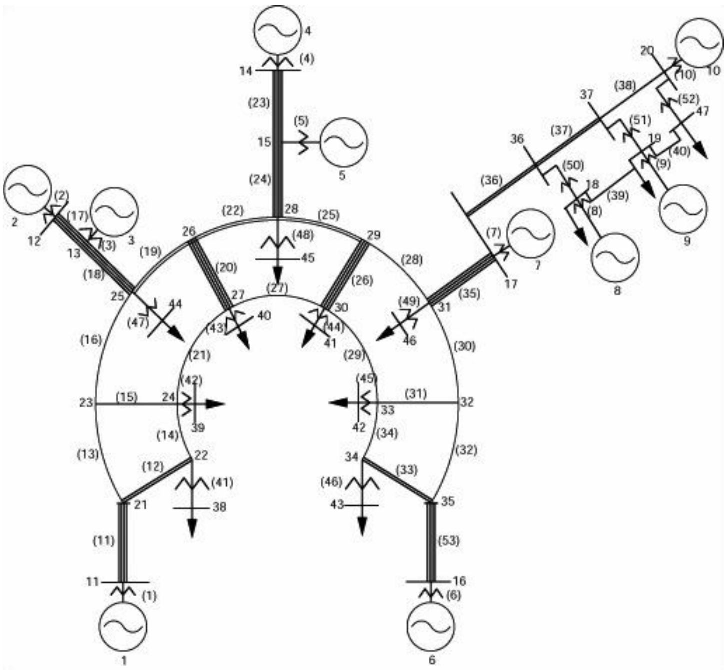

Figure 4: East Japan 10-machines model system (50 Hz system)

Table 1: Constants for generators

	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
Rated Capacity [MVA]	11,000	7,000	8,240	6,000	11,000	6,000	11,000	11,000	7,000	5,880
GOV Gain K_G [p.u.]	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
GOV Time Constant T_G [s]	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
AVR Gain K_A[p.u.]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
AVR Time Constant T_A [s]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

(Notice) Both AVR and GOV are the first order delayed systems.

Table 2: Point-to-point TTC

From-to	TTC	Violated constraint	Iteration number	Calculation time (min.)
3-18	1.00	(N-1) rule(25,25)	2	4
3-19	1.00	(N-1) rule(25,25)	2	4
3-38	2.04	(N-1) rule(12,15)	2	4
3-39	1.42	(N-1) rule(12,15)	2	4
3-40	2.64	Small-signal stability	3	6
3-41	1.32	(N-1) rule(25,25)	2	4
3-42	1.19	(N-1) rule(25,25)	2	4
3-43	1.18	(N-1) rule(25,25)	2	4

3-44	3.69	Small-signal stability	4	8
3-45	2.67	Small-signal stability	4	8
3-46	1.00	(N-1) rule(25,25)	2	4
3-47	1.00	(N-1) rule(25,25)	2	4

Table 3: Limits of generator outputs

	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
Upper bound [p.u.]	7.0	11.0	10.0	11.0	8.0	11.0	6.0	11.0	7.0	5.0
Lower bound [p.u.]	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

Table 4: TTC from group 1

To	TTC	Generator outputs			Violated constraint	Iteration number	Calculation time (min.)
		P_{m1}	P_{m2}	P_{m3} *(slack)*			
18	1.13	7.00	5.00	6.80	(N-1) rule(25,25) , P_{m1}	2	5
19	1.13	7.00	5.00	6.80	(N-1) rule(25,25) , P_{m1}	2	5
38	2.11	5.17	5.00	9.69	(N-1) rule(12,15) (19,16)	2	5
39	1.51	4.53	4.70	10.00	(N-1) rule(12,15)(19,16) , P_{m3}	3	8
40	2.66	5.86	5.80	8.75	(N-1) rule(12,15) , Small-signal	4	10
41	1.49	7.00	5.00	7.21	(N-1) rule(25,25) , P_{m1}	2	5
42	1.35	7.00	5.00	7.07	(N-1) rule(25,25) , P_{m1}	2	5
43	1.33	7.00	5.00	7.05	(N-1) rule(25,25) , P_{m1}	2	5
44	3.73	6.37	5.98	9.11	Small-signal	4	10
45	2.71	6.15	5.25	9.02	Small-signal	4	10
46	1.13	7.00	5.00	6.83	(N-1) rule(25,25) , P_{m1}	2	5
47	1.13	7.00	5.00	6.79	(N-1) rule(25,25) , P_{m1}	2	5

Table 5: TTC from group 2

To	TTC	Generator outputs				Violated constraint	Iteration number	Calculation time (min.)
		P_{m3} *(slack)*	P_{m4}	P_{m5}	P_{m6}			
18	2.88	5.66	6.43	8.00	8.44	(N-1) rule(25,25) , small-signal, P_{m5}	5	14
19	2.86	5.66	6.83	7.60	8.42	(N-1) rule(25,25) , small signal	5	14
38	3.12	5.66	7.00	8.00	8.25	(N-1) rule(24,24) (33,33) , P_{m5}	4	11
39	2.59	5.66	7.82	6.59	8.25	(N-1) rule(12,15)(33,33)	4	11
40	3.15	5.66	7.00	8.00	8.24	(N-1) rule(24,24) (33,33) , P_{m5}	4	11
41	3.10	5.66	6.98	8.00	8.21	(N-1) rule(25,25) (33,33) , P_{m5}	4	11
42	1.89	5.66	6.77	8.00	7.18	(N-1) rule(25,25) (33,31) , P_{m5}	3	8
43	1.96	5.66	6.75	8.00	7.27	(N-1) rule(25,25) (33,33) , P_{m5}	3	8
44	3.21	5.66	7.00	8.00	8.26	(N-1) rule(24,24) (33,33) , P_{m5}	4	11
45	3.26	5.66	7.00	8.00	8.30	(N-1) rule(24,24) (33,33) , P_{m5}	4	11
46	2.96	5.66	6.45	8.00	8.55	(N-1) rule(25,25) (33,33) , P_{m5}	5	14
47	2.88	5.66	6.83	7.60	8.45	(N-1) rule(25,25) , small-signal	5	14

Table 6: TTC from group 3

To	TTC	Generator outputs					Violated constraint	Iteration number	Calculation time (min.)
		P_{m3} *(slack)*	P_{m7}	P_{m8}	P_{m9}	P_{m10}			
18	2.38	5.66	6.00	4.76	5.60	4.03	Transient, small-signal, P_{m7}	6	19
19	4.48	5.66	6.00	4.88	6.80	4.78	Transient, small-signal, P_{m7}	3	10
38	1.72	5.66	6.00	4.09	5.60	4.11	Transient, small-signal, P_{m7}	6	19
39	1.72	5.66	6.00	4.10	5.60	4.10	Transient, small-signal, P_{m7}	6	19
40	1.72	5.66	6.00	4.13	5.60	4.06	Transient, small-signal, P_{m7}	6	19
41	1.70	5.66	6.00	4.17	5.60	4.00	Transient, small-signal, P_{m7}	6	19
42	1.66	5.66	6.00	4.15	6.00	3.57	Transient, (N-1) rule (33,31), P_{m7}	2	6
43	1.69	5.66	6.00	4.12	5.80	3.85	Transient, small-signal, P_{m7}	4	13
44	1.76	5.66	6.00	4.08	5.60	4.13	Transient, small-signal, P_{m7}	6	19
45	1.75	5.66	6.00	4.13	5.60	4.06	Transient, small-signal, P_{m7}	6	19
46	1.70	5.66	6.00	4.24	5.60	3.93	Transient, small-signal, P_{m7}	6	19
47	4.78	5.66	6.00	4.80	7.00	5.00	Transient, P_{m7}, P_{m9} , P_{m10}	4	13