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The Problem of Equivalent Power Sources in a Interconnected Power System during Transient State.

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It takes a considerable amount of time and labour to analyze the transient stability problems of the multi-machine system.

Therefore, in analyzing, it is desired that the system is reduced to a simple system, and, if possible, to a two-machine system which can be analyzed most easily.

But, in this case, the bundling of power sources placed far apart from each other becomes necessary, and the criterion of judgement on the propriety of its equivalent power source by bundling must be established. In this paper, the authors make a proposal of this criterion, and, applying it to several examples, prove its appropriateness, and, in conclusion, show that, in most cases, the multi-machine system can be reduced to the two-machine system by proper judgement.

1. Introduction

The existing or projected electric power system is usually a multi-machine system which a great number of machine groups are interconnected, and it takes a considerable amount of time and labour to analyze the transient stability problems of such a system.

Therefore, in analyzing, it is desired that the system is reduced possibly to a simple equivalent system.

The authors presented previously a proper method[1)] about this problem, and, at that time, treated mainly the reduction of adjacent power sources to a equivalent power source.

But, furthermore, if it is possible to reduce reasonably the general multi-machine system to a equivalent two-machine system, the analysis of that system will be simplified extremely. In this case, the problem of the equivalent power source formed by bundling of distant machine groups must be investigated, and it may be classified substantially as the following.

(1) The equivalent power source formed by bundling of distant machine groups (for instance, water power stations far apart from each other) with a fault at a common point on receiving side viewed from each group.

(2) The equivalent power source formed by bundling of distant machine groups consisting of machine groups at receiving and sending side which are interconnected through the long distance transmission lines. And, say, at this time, a fault occurs at sending end of another power source far apart from the above equivalent power source. In the latter case, the machine groups reduced to the equivalent power source differ

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from each other in characteristics, and, generally, the effect of the fault occurring at the sending side is more severe than that at the receiving side. Therefore, in determining such as the switching time, the latter equivalent source becomes more important as the subject of investigation.

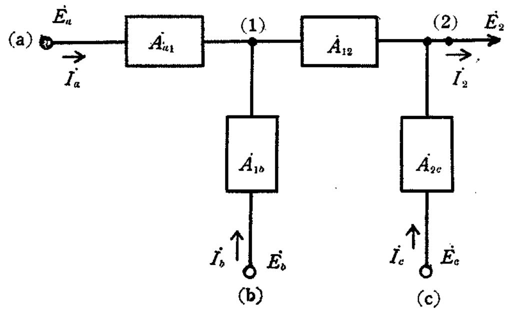
The authors presented previously a graphical method analyzing the transient stability problems of general two-machine system[2], and now expect that this method may be applied, with good advantage, to the analysis of the same problems of general power system by using the equivalent power source given in this paper.

2. The Method of Bundling of Machine Groups and the Judgement on Its Appropriateness.

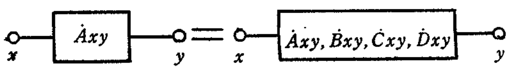
These subjects were presented in detail in the reference (1), so only the essential points will be shown here.

(1) The Method of Bundling of the Machine Groups. (Equivalent Power Sources)

Consider the multi-machine system consisting of a combination of four terminal networks as show in Fig. 1. The current I_2 flowing out from the point (2) is as follows,



Notes:—

1) 

2) The positive direction of current flow is indicated by the arrow.

Fig. 1

$$\dot{I}_2 = 1/\dot{B}_{a2}(\dot{E}_a + \dot{B}_{a1}/\dot{B}_{1b}\cdot\dot{E}_b + \dot{B}_{a2}/\dot{B}_{2c}\cdot\dot{E}_c) - \dot{A}_{a2}/\dot{B}_{a2}\cdot\dot{E}_2$$

$$= 1/\dot{B}_{a2}\cdot\dot{E}'_\varepsilon - \dot{A}_{a2}/\dot{B}_{\lambda 2}\cdot\dot{E}_2 = \frac{\dot{E}_\varepsilon - \dot{E}_2}{(\dot{B}_{a2}/\dot{A}_{a2})} \qquad (1)$$

where, $\dot{E}_a$, $\dot{E}_b$ and $\dot{E}_c$ are voltages behind transient reactance of each machine a, b and c, respectively, and

$$\dot{E}'_\varepsilon = \dot{E}_a + \dot{B}_{a1}/\dot{B}_{1b}\cdot\dot{E}_b + \dot{B}_{a2}/\dot{B}_{2c}\cdot\dot{B}_c,$$

$$\dot{E}_\varepsilon = \dot{E}'_\varepsilon/A_{a2}$$

By this procedure the machine groups shown in Fig. 1 are reduced to a single machine or power source with the internal voltage $\dot{E}_\varepsilon$ and impedance $\dot{B}_{a2}/A_{a2}$ as shown in Fig. 2. And its apparent inertia constant at the moment of fault is given by the following equation,

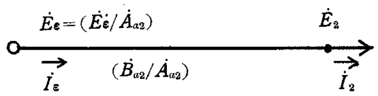


Fig. 2

$$M_\varepsilon \simeq \frac{E'_\varepsilon \Delta P_{\varepsilon 0}}{E_A \cos\theta_{\varepsilon a}\Delta P_{a0}/M_a + E_B\cos\theta_{\varepsilon b}\Delta P_{b0}/M_b + E_C\cos\theta_{\varepsilon c}\Delta P_{c0}/M_c} \qquad (2)$$

where, E_A, E_B and E_C are $|\dot{E}_a|$, $|\dot{B}_{a1}/\dot{B}_{1b}\cdot\dot{E}_b|$ and $|\dot{B}_{a2}/\dot{B}_{2c}\cdot\dot{E}_c|$, $\theta_{\varepsilon a}$, $\theta_{\varepsilon b}$ and $\theta_{\varepsilon c}$ are phase differences between $\dot{E}'_\varepsilon$ and $\dot{E}_a$, $\dot{B}_{a1}/\dot{B}_{1b}\cdot\dot{E}_b$ and $\dot{B}_{a2}/\dot{B}_{2c}\cdot\dot{E}_c$, M_a, M_b and M_c are inertia constants of each machine a, b, and c, ΔP_{a0}, ΔP_{b0} and ΔP_{c0} are instantaneous power changes of each machine a, b, and c before and after a fault, respectively, and $\Delta P_{\varepsilon 0}$ is that of the equivalent machine.

If the voltage E'_ε can be regarded as follows,

$$E'_\varepsilon = |\dot{E}_A+\dot{E}_B+\dot{E}_C| \simeq |\dot{E}_A|+|\dot{E}_B|+|\dot{E}_C| \qquad (3)$$

the equation (2) becomes

$$M_\varepsilon \simeq \frac{E'^2_\varepsilon}{E_A^2/M_a+E_B^2/M_b+E_C^2/M_c}. \qquad (4)$$

This equation can be used almost without error for many cases.

(2) **The Judgement on the Appropriateness of the Equivalent Power Source.** In order that the machine groups may be reduced without error to the equivalent source, it is necessary that the voltages behind transient reactances of all groups forming the equivalent source maintain a same phase displacement with respect to one another during the period considered. In the study of transient stability, this is equivalent to assuming that the disturbance does not produce any effect which will cause the machine groups in the equivalent source to take new angular displacements with respect to one another. Theoretically, this condition can be realized only when a fault causes a net torque on each machine group which is proportional to its inertia constant, and then the apparent inertia constant of its eqivalent source is equal to an arithmetic sum M_t of inertia constants of all machine groups forming it.

But, generally, as the machine groups can not maintain the same phase displacement, the internal voltage and the apparent inertia constant of the equivalent source must change at every moment, and then the apparent inertia constant represented by M_ε given in equations (2) and (4) can be justified only at a moment of the fault.

But if the above M_ε is nearly equal to M_t, it may be expected reasonably taat the all machine groups forming the equivalent source must swing together with a same motion. Therefore, the condition represented by $M_\varepsilon/M_t=1$ will become one of the criterion by which the appropriateness of the equivalent source may be judged.

Next, the synchronizing powers between each machine group must be considered, too. That is, if the large synchronizing powers remain during a fault, the miss of the condition will be corrected gradually in course of time, while if their powers are small, the miss will become gradually larger.

Therefore, in order to judge the appropriateness of the equivalent source, it is necessary that the condition of the inertia constant represented by $M_e/M_t=1$ is considered including the synchronizing powers.

3. The Equivalent Power Source Formed by Bundling of the Distant Machine Groups with a Fault at a Common Point on Receiving Side Viewed from Each Group.

(1) General Consideration. Now, if it is assumed that the conditions of the allotted powers and the inertia constants of the machine groups forming the equivalent source are as shown in the second and third column of Table 1 respectively, the conditions of the apparent inertia constant of the equivalent source will become as shown in the last column according to the above conditions. And, since the accelerating or decelerating rate of each machine during the fault is proportional to its power difference between input and output and inversely proportional to its inertia constant, it is anticipated that machine groups with swing together with the same motion in the case 1 and will not in the cases 2 and 3.

Table 1.

No. of case	Allotted powers	Inertia constants	Conditions
1	balance	balance	good
2	unbalance	〃	bad
3	balance	unbalance	〃

But, in the condition being discussed here, as the synchroniging powers between machine groups will be poor extremely in all cases shown in Table 1, in either case the miss of condition will become gradually larger in course of time.

Therefore, in this case, the condition of the apparent inertia constant of the equivalent source is required to be very severe.

(2) Consideration by Examples. The system represented in Fig. 3 will be used to consider the above equivalent source. The machine groups (a) and (b) are connected to the load area by the long distance transmission lines, and it is assumed that a line-to-line fault occurs at the low-or high-tension bus of the primary substation.

Various conditions are as shown in Table 2, and the phase difference vs time curves in Fig. 4 to 7 for eoch case in this table. The condition is very good in the case 1 since the allotted powers and the inertia constants are balanced. Therefore, in such a case, even if the problems of the transient stability are studied by the equivalent source, their results are very exact as shown in Figs. 4 and 7. But, in the case 2 or 3, as the allotted powers or the inertia constants are out of balance, the miss of condition

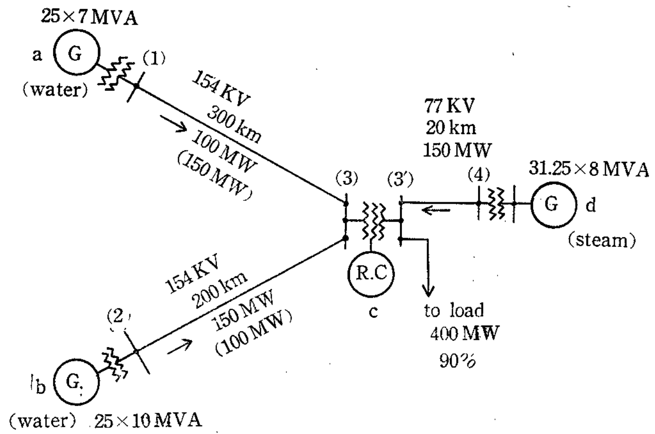


Fig. 3

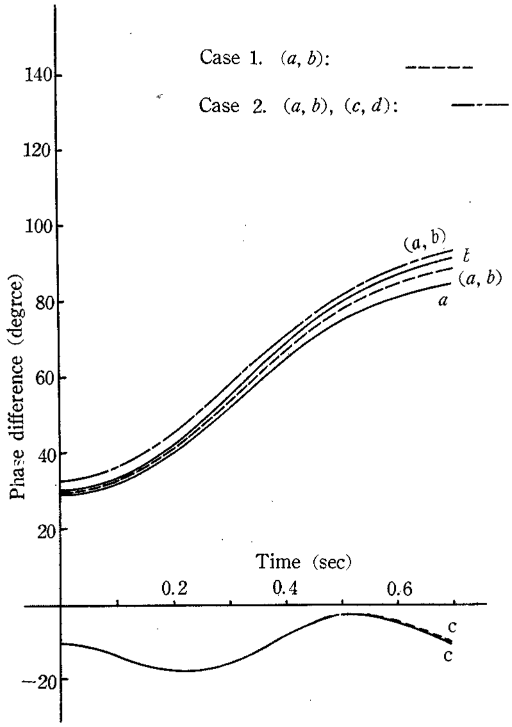


Fig. 4.

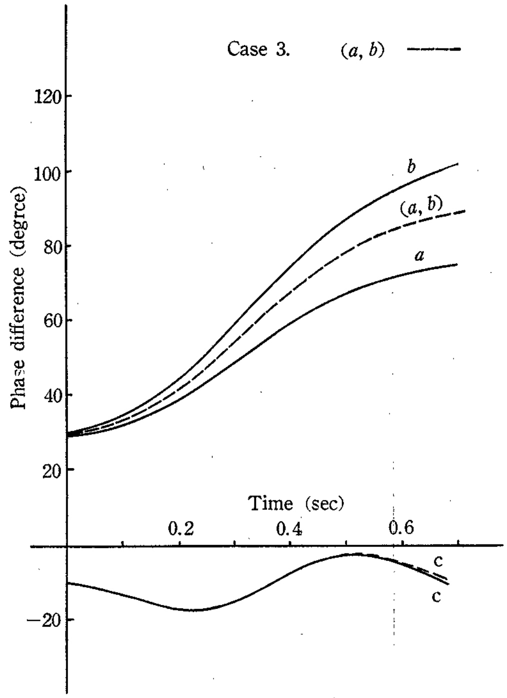


Fig. 5

for the apparent ineatia constant comes out, and, moreover, the bad condition of poor synchronizing powers is added, therefore, though this miss of condition is a little, it causes a large error as shown in Figs. 5 and 6. But such a condition is seldom in the practical system.

Table 2.

No. of case	Fault points	Allotted powers of water group	Inertia constants of water group	Equivalent sources	Criterions on judgement	
					M_e/M_t	Synchronizing powers
1	(3′)	a: 100MW, b: 150 〃 } balance	a: 5.2, b: 5.2 } balance	(a, b)	1.00	small
2	〃	〃	〃	(a, b)	1.00	〃
				(c, d)	0.79	very large
3	〃	〃	a: 5.77, b: 4.8 } unbalance	(a, b)	0.99	small
4	〃	a: 150MW, b: 100 〃 } unbalance	same with case 1	(a, b)	0.98	〃
5	(3)	same with case 1	〃	(a, b)	1.00	〃
6	〃	〃	〃	(b, c, d)	0.80	large

Note:— Inertia constants given in the fourth column are calculated under the common base 100 MW.

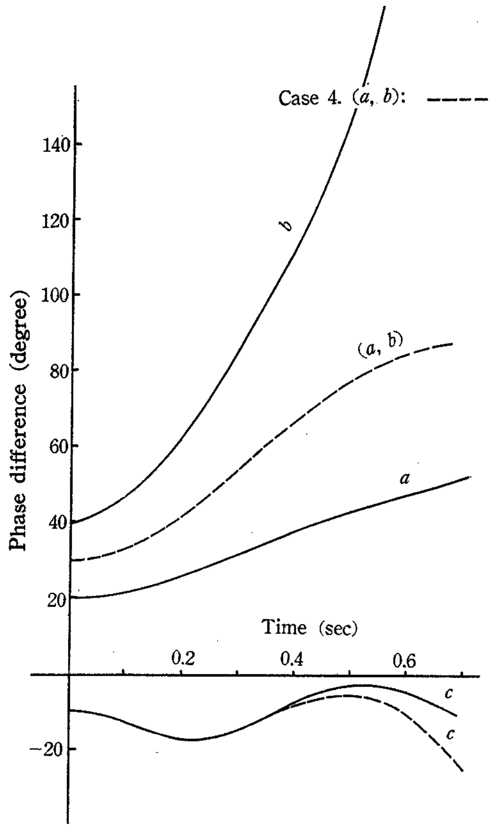


Fig. 6

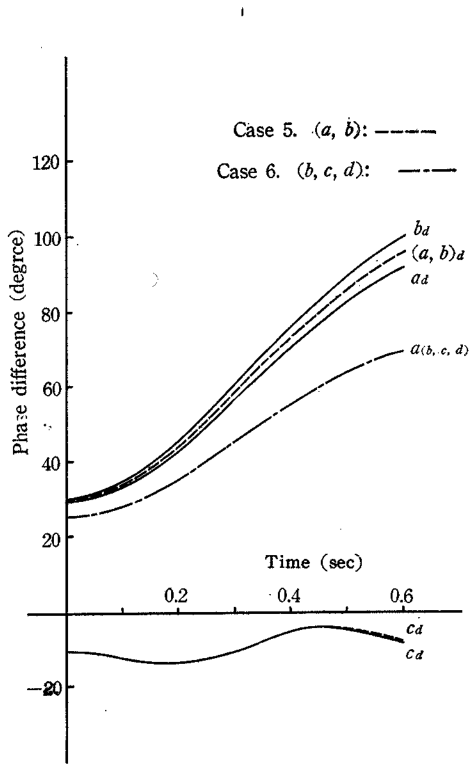


Fig. 7

Therefore, in ordinary circumstances, it is expected that the all groups in the load area (including groups *c* and *d*) will swing in one source and that the water power sources (groups *a* and *b*) will swing together, forming a second source.

4. The Equivalent Power Source Formed by Bundling of the Distant Machine Groups Consisting of Machine Group at Receiving and Sending Sides.

In this case, it is assumed that a fault occurs at sending end of another power source far apart from the equivalent power source considered here.

(1) **General Consideration.** Since a fault at sending side is generally more severe than that at receiving side, in determining such as the switching time, the equivalent source treated here becomes more important as the subject of investigation.

In this case, the machine groups forming the equivalent source differ from one another in characteristics. Therefore, it is anticipated that the miss of the condition for the apparent inertia constant is fairly large, but the synchronizing powers between the groups included in the equivalent source is large as compared with them between these groups and other groups installed beyond the fault. Consequently, in this case, it is not so severe requirement to satisfy the condition for the apparent inertia constant.

(2) Consideration by Example. The systam is the same as that shown before, except that a line-to-line fault occurs at the high-tension bus of water group (a). The equivalent source is formed by (b), (c) and (d) groups.

The phase difference vs time curves are shown in Fig. 8. The condition for the apparent inertia constant is no good (0.80), but the synchronizing powers between (b), (c) and (d) groups are fairly large as compared with them between these groups and water group (a).

Therefore, the equivalent source does not cause the error, and the all group in the load area [including groups (c) and (d)] and the water power group (b) swing together in one equivalent source as shown in Fig. 8.

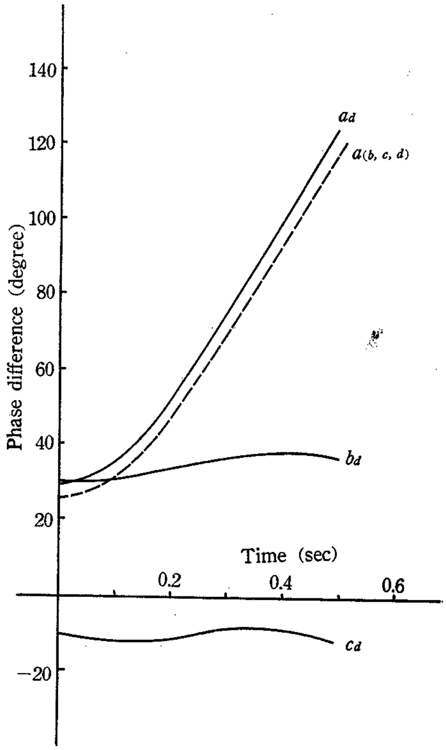


Fig. 8

5. Conclusion

Considering the operating condition of the system before the fault, the location of fault point, etc., if the method of bundling of the machine groups is proper, the multi-machine system may be reduced, in most cases, to the two-machine system. And the appropriateness of the equivalent power source formed by bundling can be fairly judged by the condition for its apparent inertia constant (that is $M_s/M_t=1$) and the synchronizing powers between machine groups included in it.

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