Dynamic Equivalents of the KEPCO System for the Stability Analysis

Hanmin Lee, Sae-hyuk Kwon, Gilsoo Jang, Byongjun Lee and Byunghun Chang

Abstract - This paper deals with the development of dynamic equivalents of the Korea Electric Corporation (KEPCO) systems. Several coherency identification methods are studied in order to find a proper method to well represent the dynamic characteristics of the KEPCO system. Also, this paper presents the comparison of the detail and classical aggregation methods in terms of the dynamic and static characteristics of the system. The nonlinear time simulation of the developed KEPCO equivalent system and the original system is performed to illustrate the validity of the equivalent system.
Keywords - dynamic equivalent system, coherency identification, DYNRED, KEPCO system

1. Introduction

Korea Electric Power Corporation (KEPCO) systems become a large-scale power system as the Korean economy grows rapidly, and the system is expected to have 65GW of generation capacity in the year of 2010. KEPCO is developing a real-time simulator based on the RTDS (Real Time Digital Simulator) in order to analyze complex behaviors of the large system in real time. For the real-time power system analysis, there exists a limitation in the scale of the simulated system, hence it is crucial to develop equivalent systems which represent well the characteristics of the original system.

For the dynamic equivalencing, a coherency based dynamic reduction method was developed by EPRI in the 1970's, and Ontario Hydro developed a new EPRI dynamic equivalencing program (DYNRED) in 1993[1]. There are three coherency identification methods in the DYNRED, which are linear time simulation method[2], weak coupling method[3], and two time scale method[4]. In this paper, a suitable coherency identification method among them to represent the crucial characteristics of the KEPCO system is investigated. The reduced systems based on the three coherency identification methods have inevitable performance differences with respect to the original system, and a method that makes the least errors between the KEPCO system and the reduced equivalent system is identified. Coherency groups are aggregated by the detail and classical methods, and the performance of both equivalent systems is compared. Finally, this paper propose a suitable equivalencing technique for the KEPCO system through the dynamic characteristic comparison of the equivalent systems with respect to the original system using various simulations.

This work was sponsored by Next-Generation Power Technology Center supported by Ministry of Science and Technology and Korea Science and Engineering Foundation.

Manuscript received: Nov. 5, 2001 accepted: Jan. 16, 2002.

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2. The Characteristics OF KEPCO SYSTEM

It is harder to find new generation sites close to demand areas in Korea, and it makes the existing generator sites have more generating units. Also, most of them are located along the coast, which are geographically far away from high load demanding area including Seoul. Therefore, KEPCO system has many long transmission lines with large amounts of power interchanged. Moreover, the system consists of heavily looped transmission systems in order to transfer large power from a remote generations to consumers reliably.

Generating units in the KEPCO system are made up of hydroelectric power plants, thermoelectric power plants, and nuclear power plants. There exist the limitations of depending on the thermoelectric power plants for the production of electric power due to the environmental considerations. Therefore, large nuclear power plants that are not concerned with the air pollution problems are presently being under construction. Until 2015, the KEPCO is going ahead with a long-term plan for facility expansion of nuclear power plants of 28,950[MW] which occupies 35.1% in the total KEPCO system capacity[5].

3. The Reduction Procedure

Equivalent systems which preserve the desired static and dynamic characteristics of the original power system are developed by the following four steps: coherency identification/grouping, generator/control system aggregation, network reduction, and the reduced equivalent system. The detail description of each step is as follows.

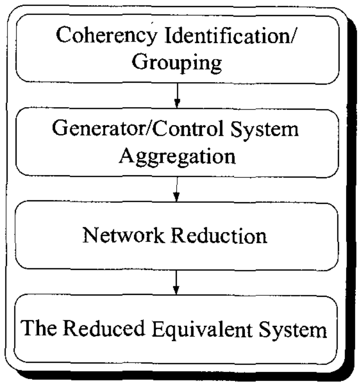

Fig. 1 The reduction procedure

The Coherency Identification stage, coherent generators are identified and grouped using the following methods.

- Linear Time Simulation Method
- Weak Coupling Method
- Two-Time Scale Method

The numerous generator control devices in a large-scale power system has different nonlinear characteristics, and it is difficult to equivalence them. Therefore, a coherent group of generators in KEPCO system will be subdivided into the subgroups of generators having the same type of controls. The subdivision is based on governors and exciters only. Division into subgroups recognizes a number of categories of exciters and governors. After the subdivisions of coherent generator groups are determined, generators are aggregated to one or a few generators. A subgroup of generators having the same control model in coherent generator groups consists of the reduced equivalent generator by summing the loads and powers. In the case of the classical model aggregation, the accuracy of the equivalents is how closely the damping of oscillations is matched to that obtained using the full system representation. The choice of the damping factor for the equivalent machines, which is a user input, has a significant effect on this performance. In this paper, we set a value of 1.0 times H that is same as the default value in DYNRED. The generator aggregation takes one of the following two forms:

- Detailed Model Aggregation: If a few or all synchronous machines in a coherent generator group have the same type of control model, they are aggregated to a detailed model with an equivalent control.
- Classical Model Aggregation: Generators in coherent generator group are aggregated to a classical model. The classical models are aggregated without control systems.

There are many types of control systems in the KEPCO system. If the poles and zeroes of the transfer function of the equivalent control system are similar to those of the sum total of transfer functions, the developed equivalent control system can be considered to represent well the characteristics of the control systems. The bode plots of the equivalent transfer function and the total transfer function are represented at Fig. 2 and 3.

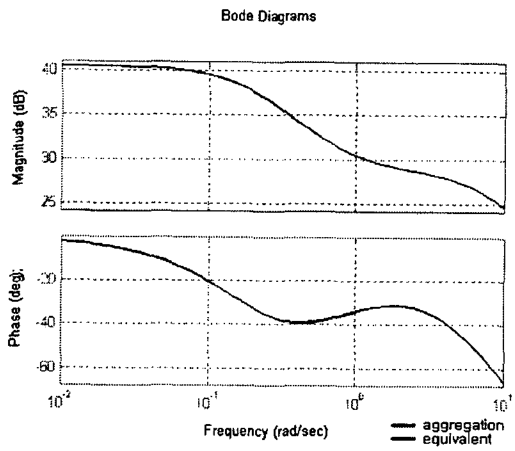

Fig. 2 Bode Plot of the Aggregated Exciter model

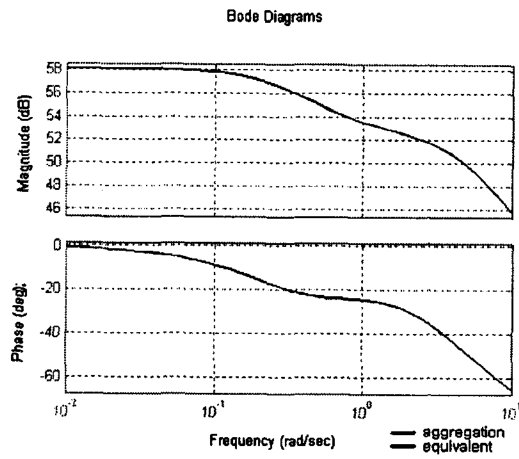

Fig. 3 Bode Plot of the Aggregated Governor-turbine model

A network reduction to a large-scale KEPCO system is performed only 154kV branch or less [6,7].

4. Kepco Equivalent System

This paper deals with the KEPCO system in 2010,which has 272 machines, 1199 buses, 848 loads, 10 types of exciter model and 6 types of governor model. Reduced equivalent systems of the large-scale KEPCO system are developed according to the three coherency identification methods. Moreover, machines having low generation are additionally equivalenced in order to reduce complex calculations and computer running time.

Three coherency identification methods and two forms of the generator aggregation are denoted as follows.

- L = Linear Time Simulation
- W = Weak Coupling
- T = Two-time scale
- D = Detailed Model Aggregation
- C = Classical Model Aggregation
- O = Original system
- R = Reduced equivalent system

Table 1 shows the grouping result based on the coherency identification methods. Descriptions of the equivalent systems are summarized in Table 2. More than 70% of the generators are reduced in the equivalent systems. Table 3 shows the total generation and load of the each reduced equivalent systems with those of the original system, and the difference among them is quite small.

Table 1 Grouping Results

	The number of Group	In a group	
		Maximum number of generator	Minimum number of generator
L	17	54	14
W	55	9	4
T	41	18	7

Table 2 Size of the Reduced Systems

		Generators	% of base	Buses	% of base
O		272	-	1199	-
R	L	60	22.1	286	23.9
	W	86	31.6	312	26.0
	T	65	23.9	291	24.3

Table 3 Performance of three method

		O		R		Δ MW (%)	Δ Mvar (%)
		MW	Mvar	MW	Mvar		
L	generation	64922	19630	64124	18133	1.2	8.3
	load	63970	25528	63376	27527	0.9	7.3
W	generation	64922	19630	64150	19052	1.2	3.0
	load	63970	25528	63379	27530	0.9	7.3
T	generation	64922	19630	64133	18802	1.2	4.4
	load	63970	25528	63377	27528	0.9	7.3

Also the weak coupling method are slightly better than the other coherency methods.

4.1 Static Characteristic Comparison

A three-phase fault was applied to the transmission line between Dong-Seoul(2500) bus and Sin-Wonju(5800) bus for the contingency study. Table 4 and 5 show the results of the simulation for the case in the systems, and voltage angles, magnitude, and active and reactive power are shown. The weak coupling method made closer response to the original system.

Table 4 Comparison of Voltages and angles

Bus number			1200	5500	7100
O		Voltage ∠Angle	1.02 ∠-24.7	1.01 ∠-11.2	0.98 ∠-2.59
R	L	Voltage ∠Angle	1.03 ∠-21.8	1.01 ∠-10.0	0.99 ∠-1.81
	W	Voltage ∠Angle	1.02 ∠-24.2	1.01 ∠-10.7	0.99 ∠-2.20
	T	Voltage ∠Angle	1.02 ∠-24.8	1.01 ∠-11.0	0.99 ∠-3.33

Table 5 Comparison of power flows

branch			2400 -2600	4400 -6950	4800 -4900
O		MW	375.4	-1337.9	-328.5
		Mvar	-118.7	70.9	35.0
R	L	MW	329.7	-1322.1	-311.0
		Dif	45.7	15.8	17.5
		Mvar	-129.5	61.8	27.2
		Dif	10.8	9.1	7.8
	W	MW	373.9	-1335.4	-327.8
		Dif	1.5	2.5	0.7
		Mvar	-119.4	69.4	34.7
		Dif	0.7	1.5	0.3
	T	MW	376.5	-1328.1	-323.9
		Dif	1.1	9.8	4.6
		Mvar	-120.0	67.3	29.0
		Dif	1.3	3.6	6

4.2 Dynamic Characteristic Comparison

In case the fault occurs at a bus or a transmission line in the vicinity of nuclear power plants, it may have a severe effect on the system. Therefore, a three-phase fault at the transmission line between YounggwangNP#1 (7150) bus connected to Younggwang nuclear power plants and Gwangsan3(7300) bus is selected for the dynamic characteristic comparison. The simulation results of the rotor angle of Sochon-#1G(26821) plant with respect to reduced equivalent systems are compared in Fig. 4 ~ 7.

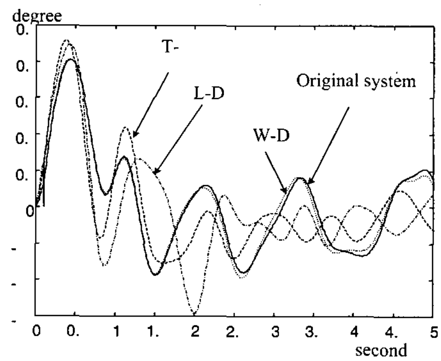

Fig. 4 Comparison of D model

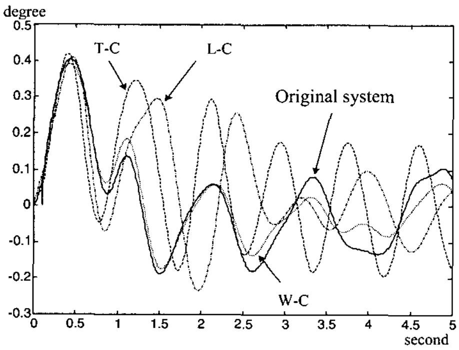

Fig. 5 Comparison of C model

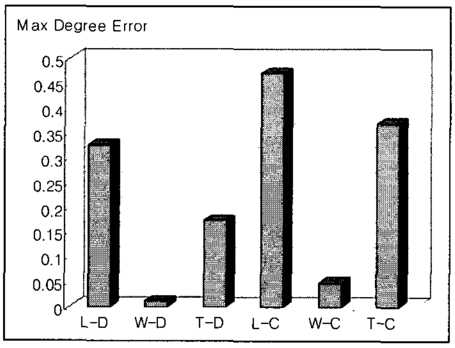

Fig. 6 Comparison of maximum degree error

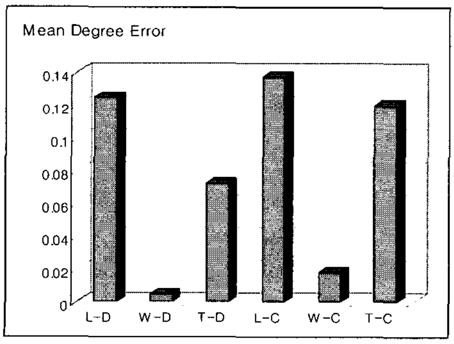

Fig. 7 Comparison of mean degree error

Fig. 4 and 5 show the rotor angle of generator using a combination of coherency identification and generator aggregation methods with respect to original system. Fig. 6 and 7 compare the maximum and mean degree(relative degree) error of generator. The weak coupling method is more closely match the original system than the other coherency methods.

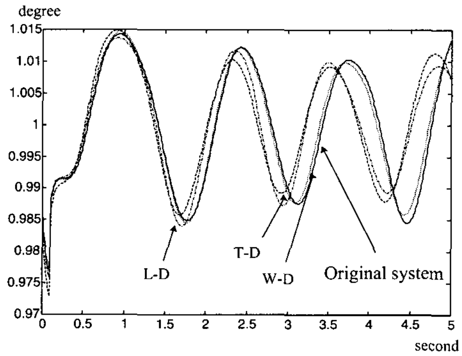

Fig. 8 Comparison of D model

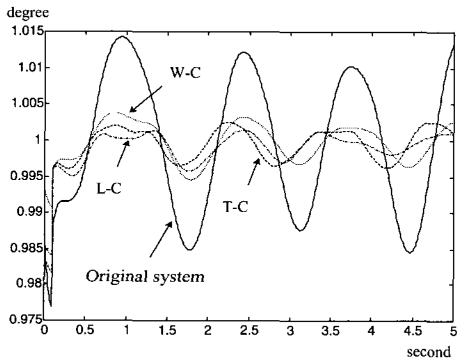

Fig. 9 Comparison of C model

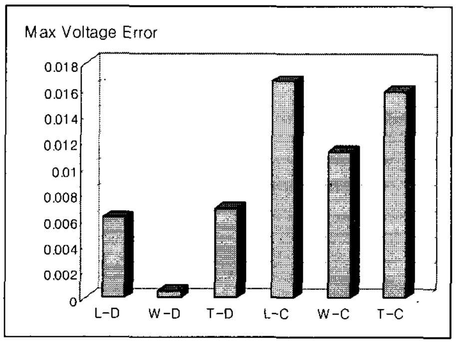

Fig. 10 Comparison of maximum voltage error

The next results are the dynamic simulation regarding the voltage magnitude of #23476 bus by a three phase fault.

For the detailed model, Fig. 8 shows that the coherency identification methods dose not significantly influence the performance of the reduced equivalent models. On the other hand, from Fig. 10 and 11, the models of the detailed aggregation to the original system have lower errors than those of the classical aggregation and represent very

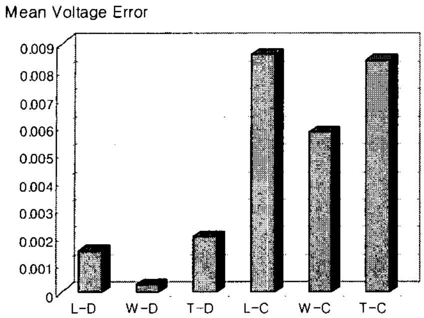

Fig. 11 Comparison of mean voltage error

closely the characteristic of the original system. The re sponse from the reduced equivalent system created by the weak coupling method is very closer than the cases that were created by using the different coherency methods from the results. To extend the case study, Fig. 12 and 13 show the mean error of the rotor angle of generators and bus voltage, taking into account the 7 contingencies. Consequently the weak coupling method made by the detailed model are suitable to the large-scale KEPCO system in 2010.

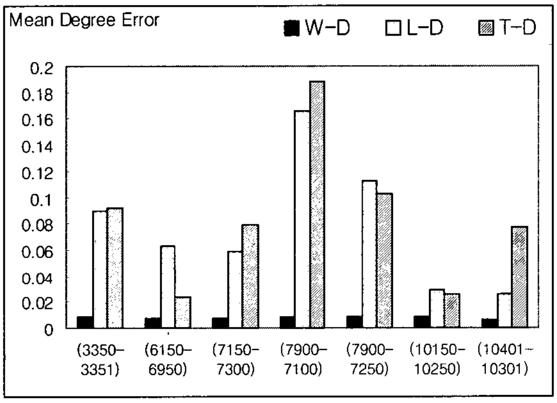

Fig. 12 Comparison of mean degree error

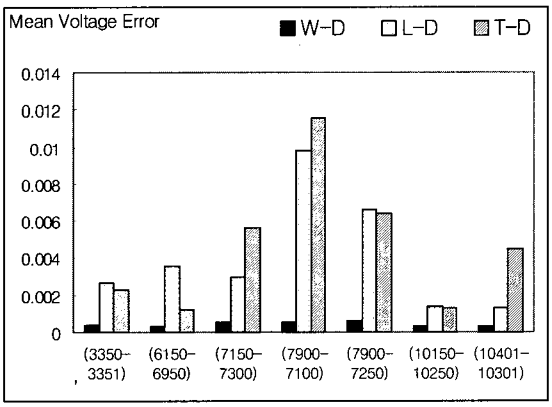

Fig. 13 Comparison of mean voltage error

5. Conclusion

This paper presented the reduced equivalent systems to a large-scale KEPCO system in 2010 by applying coherency identification methods. The reduced equivalent system obtained by the detailed aggregation based on the weak coupling method was determined to the equivalent system of the large-scale KEPCO system in 2010 by comparing a combination of coherency identification methods and generator aggregation methods.

To verify the accuracy of the proposed method, this paper studied the contingency of a three-phase fault with respect to the major transmission lines and the transmission line in the vicinity of nuclear power plants. Comparing the results of the case study, this paper showed the reduced equivalent system obtained by the detailed aggregation based on the weak coupling method has kept most of desired characteristics of the original system.

Acknowledgments

This work was sponsored by Next-Generation Power Technology Center supported by Ministry of Science and Technology and Korea Science and Engineering Foundation.

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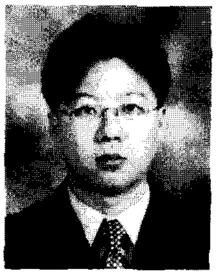

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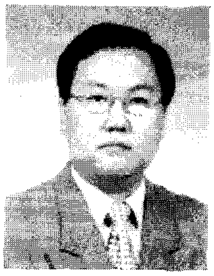

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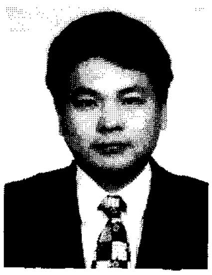

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