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DYNAMIC SIMULATIONS OF ELECTRIC POWER SYSTEMS UNDER LONG-TERM CHANGE IN SYSTEM GENERATIONS AND LOADS

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ABSTRACT

A computer program for dynamic simulations of electric power systems under long-term change in system generations and loads is proposed and at developmental stage in our research institute. The long-term here means the time-span up to one-day. The proposed program is designed to simulate not only slow dynamics but also fast dynamics under specified change in power consumption at each load node and supply from each generator. The slow dynamics implies the long-term change in node voltages, branch flows and system frequency in normal conditions with active power control and reactive power control. The fast dynamics mainly implies the angle stability at system fault conditions. The aim of the program is to support operators in planning system operations and controls. In this paper, features of the program at present time are mentioned and simulation examples are demonstrated.

KEY WORDS

Power system, long-term dynamic simulation, slow and fast dynamics, angle stability, active power control, reactive power control

1. Introduction

In the liberalization of electric power transaction, the active power will be treated separately from the reactive power. From viewpoint of the electric power supply security, however, it is necessary to consider the security in system fault conditions as well as the active power control and reactive power control in normal conditions at one time. In Japan, transmission transfer capability is mainly restricted by the angle stability since configuration of the transmission network is generally longitudinal. In this sense, the main concern in the security is the angle stability. In addition, more severe operations of power systems will be requested from the need of more effective uses of existing power apparatus.

In these situations, for technical studies on more proper operations of power system, dynamic simulation method for integrated simulations of the angle stability, the active power control and the reactive power control becomes essential.

However, the conventional simulation method for the active power control is not able to present the angle stability and behaviour of the reactive power, voltages and branch flows. In the method, all of the system load and generation are connected to the same node, and only average system frequency is calculated with difference between system loads and generations.

As for the conventional simulation method for the reactive power control is not able to represent the angle stability and behaviour of the active power control and frequency. In the simulation, the load flow calculation is generally used.

On the other hand, in the proposed program, to ensure the accuracy of the angle stability simulation, basically same

Table 1 Comparison of proposed computer program with conventional methods

	Degree of modeling details (example of generator model)	Calculation algorithm	Approach of speed-up of long-term simulation
Proposed simulation program	Park model is used same as transient stability simulation.	Numerical integration of differential-algebraic equations is used same as transient stability simulation.	Variable time-step is used to ensure accuracy and efficient simulation.
Conventional method for reactive power control simulation	No generator model is used.	Continuous load flow is used.	Only steady-state characteristic is considered. (no dynamic characteristic)
Conventional method for active power control simulation	Only generator inertia is used.	Average system frequency is calculated.	No network effect is considered.

dynamic models as used in the short-term stability computer program. For example, Park model which is widely-used in the stability program is used for synchronous generator model of the proposed program. In addition, to make the long-term simulation efficient or speedy, a new variable time-step numerical integration algorithm is used. Adoption of other variable time-step numerical integration algorithms is seen in the previous work [1, 2]. The comparison of the developed program with conventional methods is summarized in Table 1.

Thus in the proposed program, both fast dynamics and slow dynamics can be simulated. The slow dynamics implies the long-term change in node voltages, branch flows and system frequency in normal conditions with active power control and reactive power control. The fast dynamics mainly implies the angle stability at system fault conditions.

2. Features of proposed program

Summary of simulation conditions and models of the proposed program available at the present time are shown in Table 2. In addition, the outline of structure of the program is shown in Fig. 1.
The features of the developed program are as follows.

2.1 Variable time-step numerical integration

A new numerical integration algorithm with variable time-step has been developed to achieve the high-accuracy and high-speed at the same time for the long-term simulations. The algorithm shortens the simulation time-step when fast phenomena such as the synchronous power swings occur.

The algorithm is based on the 2-stage diagonally implicit Runge-Kutta rule [3]. The rule is relatively new and has not been applied yet to power system dynamic simulations. The rule has almost same accuracy as the trapezoidal rule and better numerical stability than the trapezoidal rule when the time-step is extended [4].

Table 2 Simulation conditions and models of proposed program

Simulation conditions and models	
Conditions	Change in system generations and loads
	On-line/off-line of generator
	Time series data of generations and loads
	Transmission line fault (3LG-O-C)
Models (1)Generations	Generator (detailed Park model)
	Generator AVR
	Generator OEL
	Generator prime mover (Fossil-fired plant)
(2)Loads	Induction motor
	Constant impedance
(3)System control	Simplified voltage/reactive power control
	Simplified load frequency control

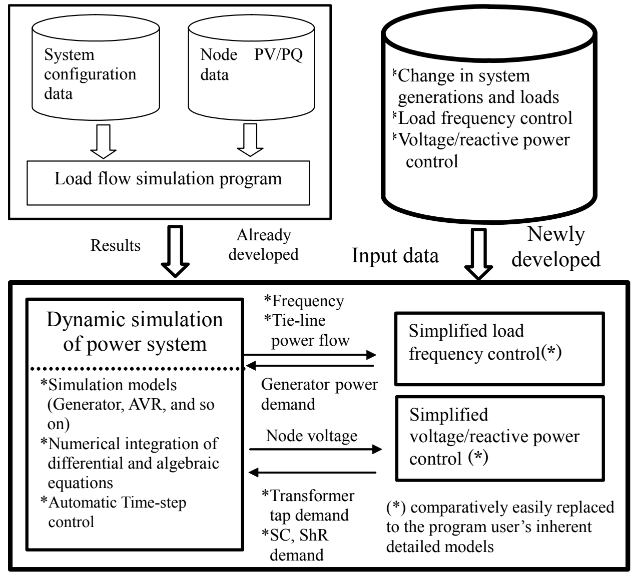


Fig. 1 Outline of structure of proposed computer program

When the differential equation and algebraic equation of the power system are expressed by (1), then the 2-stage diagonally implicit Runge-Kutta rule is expressed by equation (2).

$$\begin{aligned} \dot{x} &= f(x,v) \\ 0 &= g(x,v) \end{aligned} \tag{1}$$

$$\begin{aligned} x_{n+1} &= x_n + b_1 k_1 + b_2 k_2 \\ 0 &= g(x_{n+1}, v_{n+1}) \end{aligned} \tag{2}$$

where h is time-step

$$k_1 = hf(x_n + a_{11}k_1)$$

$$k_2 = hf(x_n + a_{21}k_1 + a_{22}k_2)$$

$$a_{11} = a_{22} = \alpha, a_{21} = \beta$$

$$b_1 = \beta, b_2 = \alpha$$

$$\alpha = 1 - 0.5\sqrt{2}, \beta = 1 - \alpha$$

2.2 Active power control and reactive power control

2.2.1 Active power control

In the proposed program, time-scheduled MW of generator output power determined by EDC (Economic Dispatching Control) is specified as input data to the program. As for the LFC (Load Frequency Control), since control logic varies among the electric utility companies in Japan, simplified model with PI control (Fig. 2) is installed in the proposed program for convenience. The model expresses the basic scheme of the control logic in Japan. However, the simple model can be comparatively easily replaced to the program-user's inherent detailed model provided by FORTRAN subroutine. This feature enables detailed simulations associated with needs of the user.

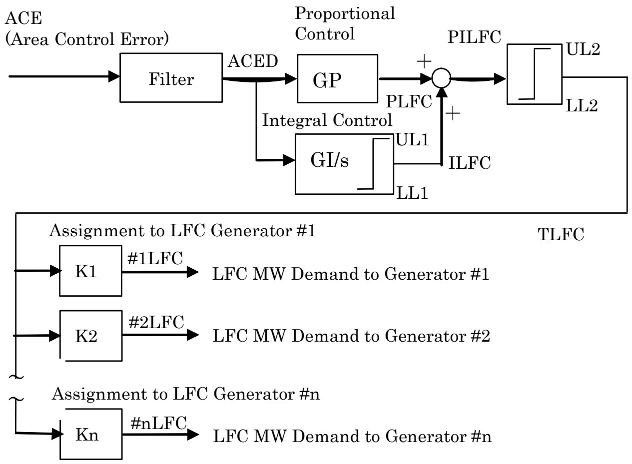


Fig. 2 Simplified model of load frequency control

(2) Reactive power control

The reactive/voltage control usually consists of the centralized control and local controls. The former is generally applied to the trunk power systems such as 150 kV to 500kV systems, and the latter is applied to 66kV or 77 kV systems in Japan.

The control logic of the centralized control widely varies among the electric utility companies, only simplified model for the control logic of the local control is installed in the proposed program for convenience. However, same as the active control model above, the simplified model can be comparatively easily replaced to the program-user's inherent detailed model including the centralized control logic.

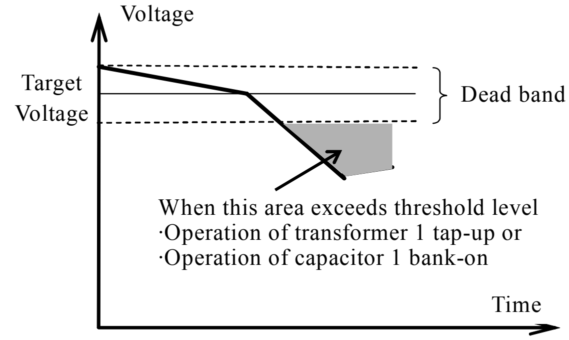
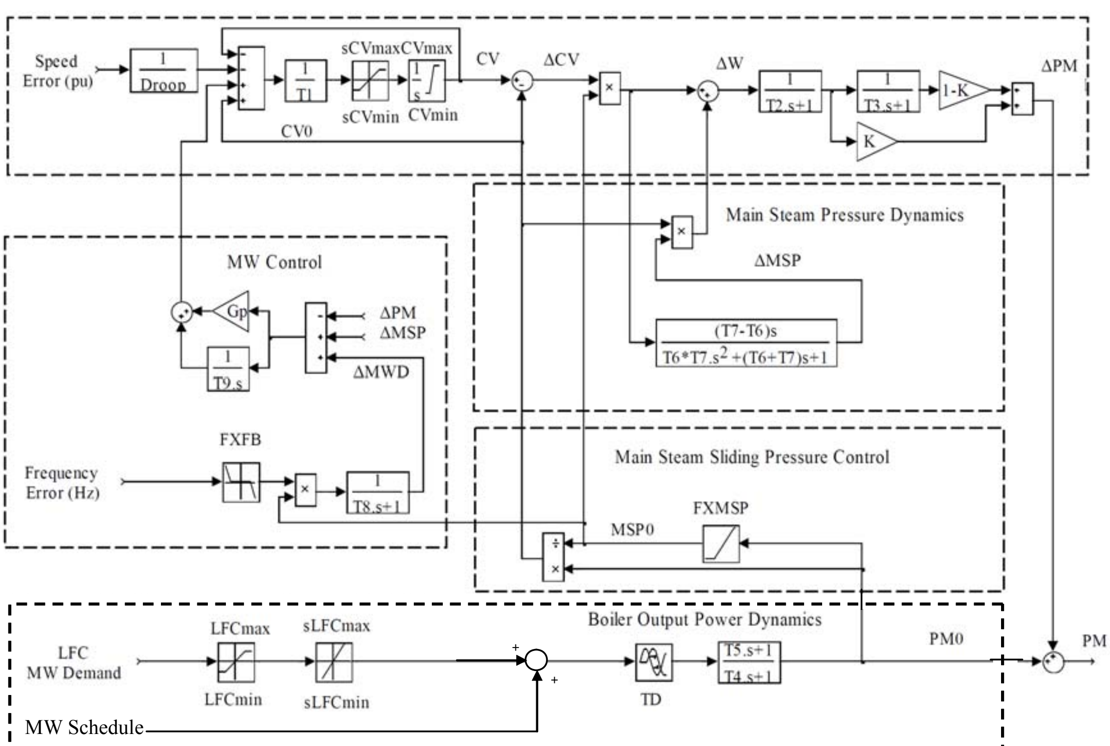


Fig. 3 Simplified model of local voltage control (voltage control based on time integration of voltage deviation at load node)

The simplified model is shown in Fig. 3. This expresses local voltage control scheme generally used in Japan.

2.3 Generator prime mover model (Fossil-fired plant model)

The main contribution to the generation control required for the active power control consisting of EDC and LFC comes from the fossil-fired power plant in Japan. Thus to represent the MW response of the fossil-fired power plant to both the time-scheduled MW and the LFC MW demand change, recently proposed our model [5] is installed in the proposed program. The model is shown in Fig. 4. In the model, not only the response of the turbine governor system but also effects of the main steam pressure and response of the boiler and its control systems are included.



PM0: Slow component of PM ΔPM : Fast component of PM (PM: Turbine mechanical power)

Fig. 4 Generator prime mover model (Fossil-fired plant model) [5]

3. Performance of proposed program

The performance of the proposed program at present time is tested with IEEJ EAST-30-generators test-power system [6]. For examples, performance in simulating the angel stability at trunk transmission line fault, and simulating the system dynamics under long-term change in generations and loads in normal conditions is presented below.

The test-power system model (30 generators, 107 nodes and 191 branches) is shown in Fig. 5. The system model represents the characteristics of the 50Hz eastern-interconnected power system in Japan.

3.1 Angle stability at transmission line fault

The angle stability is simulated when 1cct-3LG fault occurs (for 70ms) at the 2cct-branch (position A in Fig. 5) followed by re-closing of the fault line. When the re-closing time is 1.0 second after the 3LO, the angel stability is stable, while the re-closing timing is 2.0 second after the 3LO, the stability is unstable. The simulation results are shown in Fig. 6. It has been revealed that the results are same as those obtained from a transient stability computer program (called Y-method) which is widely used by all of the electric utility companies, many universities and major manufactures in Japan [6].

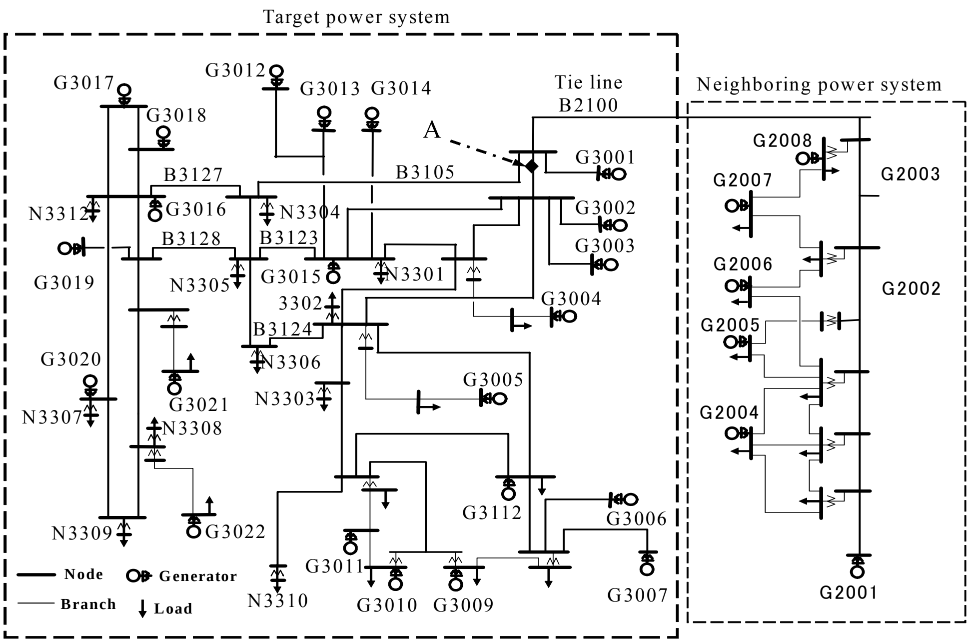
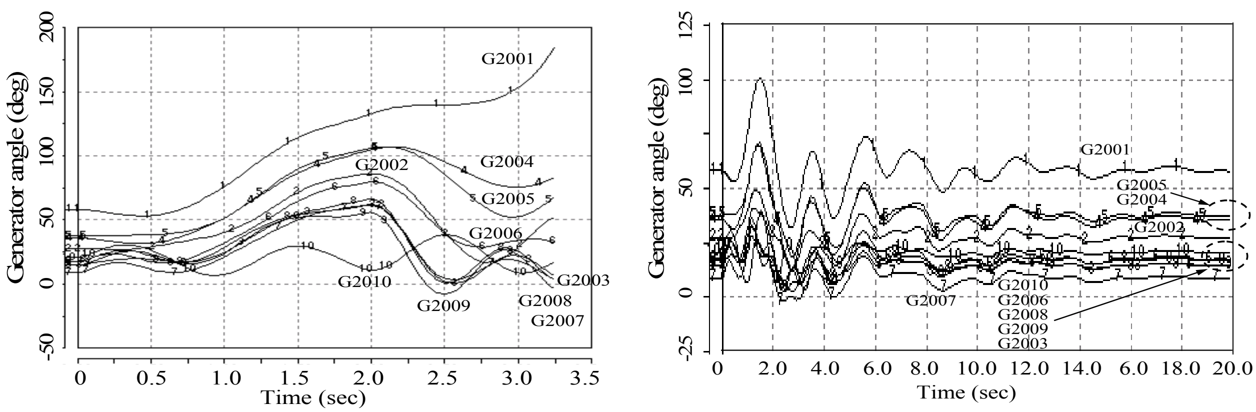


Fig. 5 IEEJ EAST-30-generators test-power system [6]



(a) Unstable case

(b) Stable case

Fig. 6 Angle stability simulation results of proposed program (1cct-3LG fault at position A in Fig. 5)

3.2 Behaviour of target power system under long-term change in generations and loads in normal condition

3.2.1 Simulation conditions

The one-hour change in system load and corresponding change in MW schedule of generation in the target system (the left hand side of Fig. 5) is assumed as shown in Fig. 7. No change in system load and generation is assumed for the neighbouring power system (the right hand side of Fig. 5).

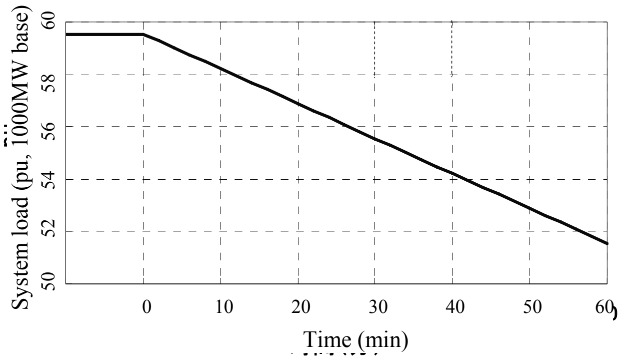
The change in system total load (Fig. 7 (a)) is distributed to each load node accordingly to the amount of the load. The change in MW schedule (Fig. 7 (b)) is assigned to 8 generators. Other 14 generator in the target system are operated with constant output power.

As for the active power and reactive power controls, simplified LFC model (Figs. 2) and simplified local voltage control (Fig. 3) at each load node are used for the sake of simplicity. Out of the above 8 generators, 4 generators are operated with LFC. All of the 8 generators are operated with primary frequency (governor) control. The generator prime mover model is used for all of the 8 generators.

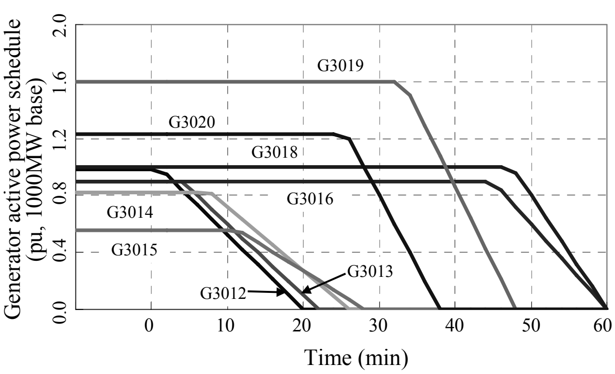
3.2.2 Simulation results

The result shows that the behaviour of the system under changes in the system generations and loads in the time frame of one-hour is simulated with around 1 to 2 minutes in CPU (Intel Celeron 1.2GHz) time.

The example of the simulated response (Fig. 8 to Fig. 12) clearly shows dynamic responses of generator active powers, node voltages, system frequency and tie-line power flows, which cannot be simultaneously presented by the conventional simulation methods.

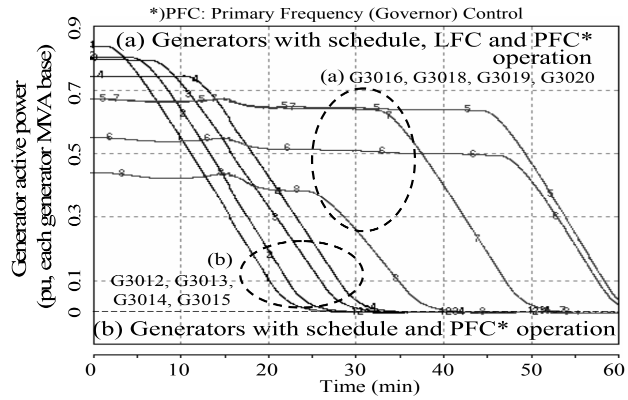


(a) Change in target system total load

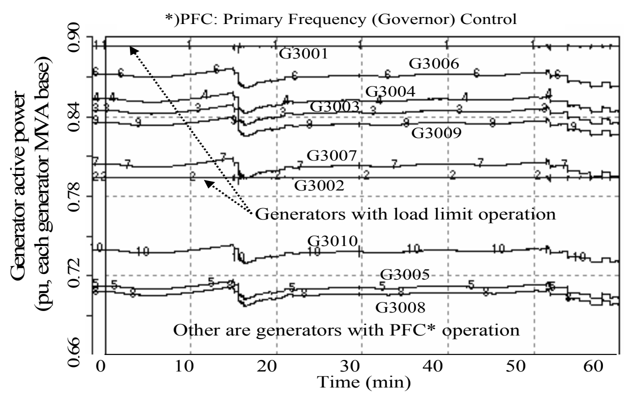


(b) Change in MW schedule of generators with output power regulation (8 generators)

Fig. 7 Assumed change in system load and MW schedule of generators (Input data to the proposed program)

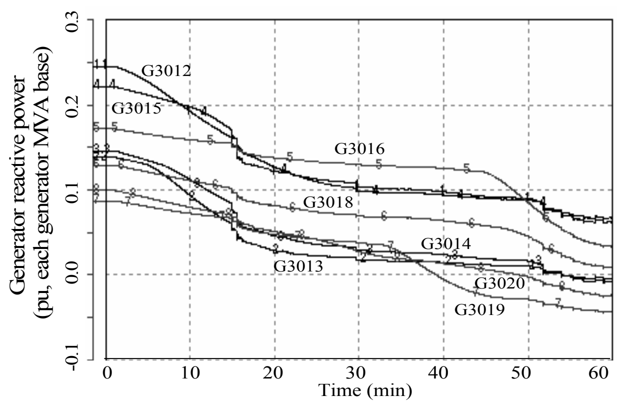


(a) Generators with output power regulation

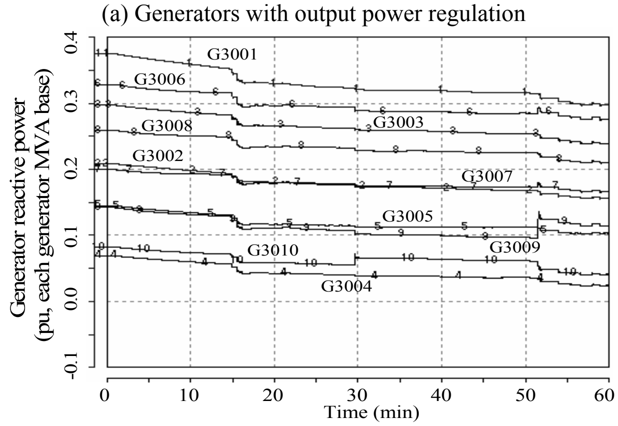


(b) Generators with constant output power (example)

Fig. 8 Generator active power change



(a) Generators with output power regulation



(b) Generators with constant output power (example)

Fig. 9 Generator reactive power change

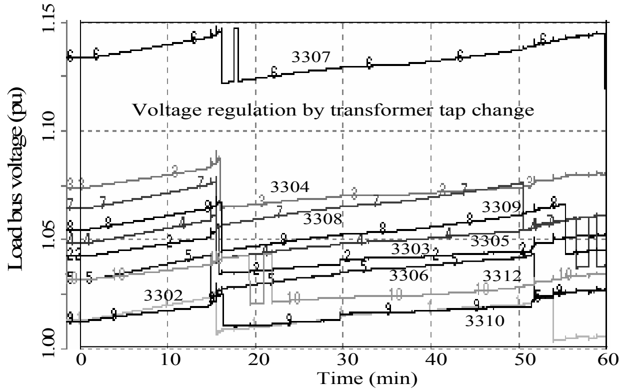


Fig. 10 Load node voltage (example)

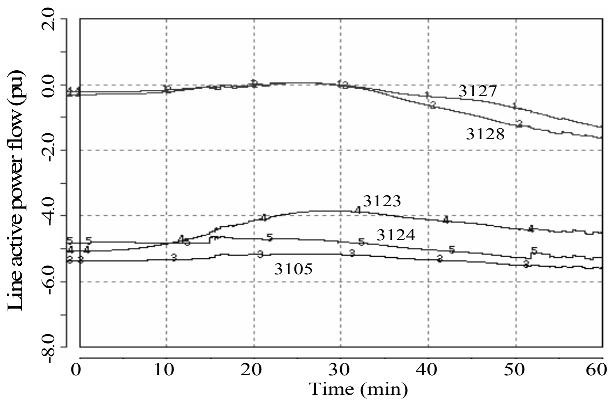


Fig. 11 Branch active power flow change (example)

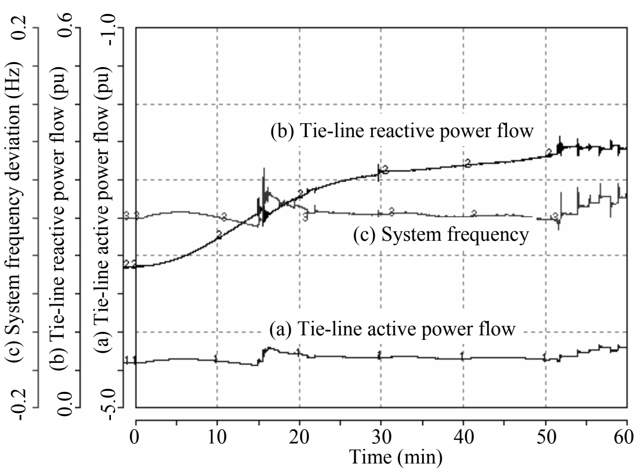


Fig. 12 Tie-line power flow and system frequency

4. Conclusion

4.1 Performance of the program

The proposed program can simulate both fast dynamics and slow dynamics with high-accuracy and high-speed. The simulation results of the test-power system with 30generator shows that the accuracy of the angle stability simulation is same as the short-term transient stability program and the behaviour of power system under change in the system load and generation in the time frame of one-hour is simulated with only around 1 to 2 minutes in CPU time.

4.2 Expected application fields of the program

The proposed program is expected to be a new tool for supporting technical studies on more accurate security control and more effective operation of power systems, including analysis of dynamic voltage stability, examination of proper generator regulation capacity for load frequency control and voltage control (Table 3).

4.3 Future Developments

After enhancing the available simulation conditions and models, the proposed program will be introduced to the electric utility companies of Japan.

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Table 3 Expected application fields of proposed computer program

Example of application fields	Advantage of proposed computer program
Effective simulation of voltage stability including dynamic behaviors of generators and loads	Dynamic simulations of the voltage stability in rapid load increase period and so on can be implemented much faster than the conventional method. In the simulations, activation of the generator over-excitation limiter and its ill effects upon the synchronous stability are included.
Technical studied on proper generator regulation capacity for load frequency control and voltage/reactive power control	Interaction between the generator active power regulation capacity for control of system frequency and tie-line power flow, and the reactive power regulation capacity for control of node voltages is able to be simulated. Thus technical studies on more effective generator regulation capacity and control scheme are available.