Transient Stability Evaluation of a 12,000-bus Power System Data Using TEPCO-BCU

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Abstract - This paper describes the evaluation results of TEPCO-BCU program on a 12,000-bus power system data. TEPCO-BCU is composed of several computation modules such as improved BCU classifiers, BCU method, BCU-guided time-domain stability program and a fast time-domain program. Current version of TEPCO-BCU is able to perform accurate stability assessment and energy margin computation of each contingency of large-scale power systems. This paper reports some experiments of this feasibility study in terms of speed and accuracy of stability assessment. In this paper we also discuss the specification of sophisticated data handling for advanced power system analysis such as TEPCO-BCU. The features of data handling consisting of graphical user interface (GUI), database (DB), script function and specification of this combination are presented in this paper.

Keywords - Dynamic security assessment, Transient stability, BCU method, Screening method, Direct method, Energy function, Critical clearing time

1 Introduction

Power systems are continually experiencing disturbances and are planned and operated to withstand the occurrence of certain disturbances. At present, modern energy management systems (EMS) periodically perform the task of on-line static security assessment that ensures the ability of the power system to withstand assumed contingencies. Static security assessment (SSA) checks the degree of satisfaction of all relevant static constraints for post-fault (post-contingency) steady states. Dynamic security assessment is concerned with power system stability/instability after contingencies. From a computational viewpoint, SSA needs to solve a large set of nonlinear algebraic equations. DSA requires the handling of a large set of nonlinear differential equations in addition to the nonlinear algebraic equations involved in the SSA.

It is desirable and is becoming necessary for modern power systems to extend EMS to include on-line dynamic security assessment (DSA). This extension is, however, a rather challenging task so that DSA has long remained an off-line task. Such extension, however, is a rather difficult task and requires several breakthroughs in analysis tools, computation methods and control schemes.

Several significant benefits can be expected from this extension. First, power systems may be operated with operational margins reduced by a factor of 10 or more if on-line, rather than off-line, DSA is performed. A second benefit of on-line DSA is that the amount of analysis can be greatly reduced by excluding contingencies which is not relevant to actual operating conditions. Several research and developments in on-line dynamic contingency screening have been reported in literature.

This paper describes an evaluation experiment of TEPCO-BCU program for large-scale power systems. An integrated computer package, named TEPCO-BCU, is a transient stability assessment program designed for large-scale power systems [1],[2]. TEPCO-BCU is composed of several computation modules such as improved BCU classifiers, BCU method, and BCU-guided time-domain program and a fast time-domain simulation program. Current version of TEPCO-BCU is able to perform exactstability assessment (i.e. classify stable contingencies as stable and unstable contingencies as unstable) and accurate energy margin computation of each contingency of large-scale power systems.

In this paper, the authors evaluated the feasibility of applying TEPCO-BCU to a 12,000-bus power system data, and reports some experiments of this feasibility study. For example, on the Pentium IV 2.7GHz, the computing time of 46% of contingency cases is less than 3.0[sec]; also the average time for processing one contingency is roughly 18[sec]. In addition, the energy margins and estimated CCTs of all contingency cases are accurately determined.

In current version of TEPCO-BCU, the excitation model of each generator has to be simplified into a one-gain-one-time-constant model. This paper presents a method to reduce a comprehensive excitation system model including PSS into the simplified one. We develop a frequency-domain method to calculate equivalent coefficient of damping factor of PSS. The accuracy of TEPCO-BCU is then evaluated on the 12,000-bus power system data by comparing its results, in which a simplified excitation system is used with the results obtained by a time-domain transient stability simulation program on a detailed excitation system model.

Finally, the sophisticated data-handling scheme is also important to the development of the TEPCO-BCU program to realize a practical on-line DSA system. Text type data-handling, which often appears in conventional type FORTRAN data handling, is not preferable. In this paper we also discuss the specification of sophisticated data handling for advanced power system analysis such as TEPCO-BCU. The features of data handling consisting of graphical user interface (GUI), database (DB), script function and specification of this combination are presented in this paper.

2 DSA Requirements

On-line dynamic security assessment (DSA) is an essential tool needed to avoid any violation of dynamic security limits. Indeed, with current power system operating environments, it is increasingly difficult for power system operators to generate all the operating limits for all possible operating conditions under a list of credible contingencies. Hence, it is imperative to develop reliable and effective on-line DSA to obtain the operating security limits at or near real-time. In addition to this important function, power system transmission open access and restructuring further reinforce the need for on-line DSA as it is the base upon which available transfer capability, dynamic congestion management problems and special protection systems can be effectively resolved. Accurate calculation of transfer capability would allow remote generators with low production cost to be economically dispatched.

Despite that the computational effort required in on-line DSA is roughly three magnitudes higher than that for on-line SSA, the recent power system operating environment motivates moving DSA from the off-line planning mode into the on-line operating environment.

To significantly reduce the computational burden required for on-line DSA, the strategy of using an effective scheme to screen out a large number of stable contingencies and to only apply detailed simulation programs to potentially unstable contingencies is well recognized. This strategy has been successfully implemented in on-line static security assessment (SSA) and can be potentially applied to on-line DSA. Given a set of some assumed contingencies, the strategy would break the task of on-line DSA into two assessment stages:

Stage 1 : Perform the task of fast dynamic contingency screening to screen out contingencies that are definitely stable from a set of some assumed contingencies

Stage 2 : Perform detailed stability assessment and energy margin calculation of each contingency remaining after Stage 1.

Dynamic contingency screening of Stage 1 is a fundamental function of an on-line DSA system. The overall computational speed of an on-line DSA system depends greatly on the effectiveness of the dynamic contingency screening, whose objective is to identify contingencies, which are definitely stable and thereby avoid further stability analysis for these contingencies. We develop the following requirements, which are essential for any candidate (classifier) intended to perform on-line static (respectively, dynamic) contingency screening for current or near future power systems [4]:

(1) reliability measure - absolute capture of insecure (respectively, unstable) contingencies; i.e. no insecure (respectively, unstable) contingencies are missed

(2) efficiency measure - high-yield of screening out the secure (respectively, stable) contingencies, i.e. the ratio of the number of secure (respectively, stable) contingencies detected to the number of actual secure (respectively, stable) contingencies is as close to 1 as possible

(3) on-line computation - little need of off-line computations and/or adjustments in order to meet with the constantly changing and uncertain operating conditions

(4) speed measure - high speed, i.e. fast classification for each contingency case

(5) performance measure - robust performance with respect to changes in power system operating conditions

Current power system operating environments call for a great need to develop a contingency screening scheme which satisfies the above five essential requirements. We point out that the artificial intelligence (AI) approach is not suitable for performing the dynamic contingency screening, due to the above essential requirements.

After Stage 1, the remaining contingencies, classified as undecided or potentially unstable, are then sent to Stage 2 for detailed stability assessment and energy margin calculation. Stage 2 is involved with detailed stability assessment and accurate energy margin calculation as well as estimation of critical clearing times. Basically, effectivemethods based on time-domain simulation can be generally applied to Stage 2 of on-line DSA.

3 TEPCO-BCU System

After decades of research and development in the direct methods, it has become clear that the time-domain method approach in stability analysis cannot be completely replaced. Instead, the capabilities of the direct methods and the time-domain method should be used to complement each other. The current direction of development is to combine a direct method and a fast time-domain method into an integrated power system stability program to take advantage of the merit of both methods. The TEPCO-BCU is developed under this direction by combining BCU method, BCU classifiers, and BCU-guide time domain method. TEPCO-BCU is an integrated computer package developed for exact transient stability assessment and accurate energy margin calculation of large-scale power systems in on-line mode or real-time study mode under a list of credible contingencies. TEPCO-BCU has been evaluated on several power system models. The core technologies of the improved BCU classifiers is the BCU (Boundary of Stability Region Controlling Unstable Equilibrium Point) method. Descriptions of the BCU method can be found in several books such as [5]-[9]. The theoretical foundation of BCU method has been established in [12],[13].

The main functions of TEPCO-BCU include the following:

* Fast stability assessments of a list of credible contingencies

* Computation of energy margin for transient stability assessment of each contingency

* BCU-based fast computation of critical clearing time of each contingency

* Fast identification of severe contingencies with zero or negative energy margins

* Contingency screening and ranking for transient stability in terms of energy margin or critical clearing time

* Detailed time-domain simulation of selected contingencies.

TEPCO-BCU computes accurate energy margin for each contingency with the following property:

Property 1: if the energy margin is greater than zero, then the corresponding post-fault system is guaranteed to be stable with respect to the provided data and model for transient stability. If the margin is less than zero, then the system may be unstable with respect to the provided data and model.

Regarding property 1, TEPCO-BCU is configurable so that if the computed margin is greater than zero, then the post-fault system is guaranteed to be stable with respect to the provided data and model for transient stability; otherwise the system is unstable. TEPCO-BCU ranks the postulated disturbance scenarios according to their severity in terms of energy margins or critical clearing time. BCU-guided time-domain stability program is used for detailed analysis of selected contingencies for verifying their stability/instability and for accurate computation of energy margin.

Another feature of TEPCO-BCU is that it provides useful information regarding the development of preventive control against transient instability should the study contingency be found unstable. This useful information includes the coordinate of the controlling unstable equilibrium point.

The architecture of the TEPCO-BCU system is shown in Figure 1, where there are two major components in the system:

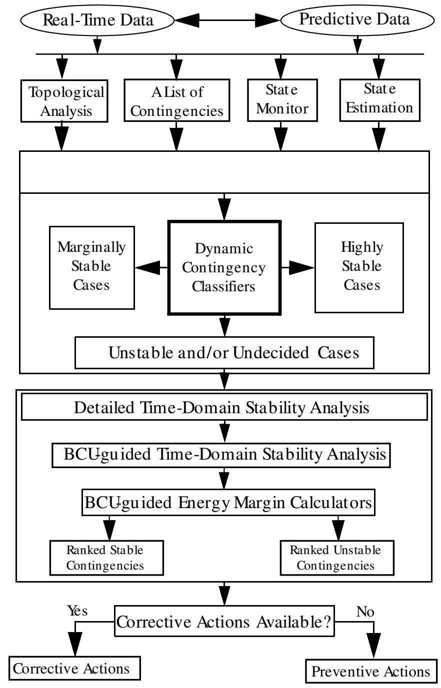

Figure 1: Architecture of BCU-DSA System

(i) Improved BCU classifiers: A dynamic contingency screening program made up of a sequence of improved BCU classifiers whose major functions are to screen out, from a set of some assumed contingencies, all of those contingencies which are definitely stable and to capture all of the (potentially) unstable contingencies. This set of improved BCU classifiers satisfies the five requirements discussed in the previous section and is used in TEPCO-BCU for performing the function of Stage 1 of on-line DSA.

(ii) BCU-guided TDS: A BCU-guided time-domain stability program for exact stability analysis and accurate energy margin calculation of both the (potentially) unstable contingencies captured by the improved BCU classifiers and the remaining undecided contingencies in (i).

When a new cycle of DSA is warranted, a list of credible contingencies along with information from the state estimator and topological analysis are first applied to the improved BCU classifiers whose basic function is to screen out contingencies which are either potentially unstable or definitely stable. Contingencies which are classified as definitely stable by the improved BCU classifiers are associated with an energy function value and then eliminated from further stability analysis. Contingencies, which are identified as potentially unstable, are then sent to the BCU-guided time-domain simulation program for further stability analysis and energy margin calculation.

4 Modeling Issues in TEPCO-BCU

The original transient stability model is composed of detailed generator model, detailed Park's model and practical exciter and PSS block diagram such as shown Figure 2, structure-preserving transmission network, and nonlinear load model. TEPCO-BCU is designed so that the controlling unstable equilibrium point (CUEP) of the following model, called "simplified model" in this paper can be calculated.

Generator model of "simplified model":

$$T'_{d0}\frac{dE'_q}{dt} = E_{fd} - E'_q + (X_d - X'_d)I_d \quad (1)$$

$$T'_{q0}\frac{dE'_d}{dt} = -E_d - (X_q - X'_q)I_q \quad (2)$$

$$M\frac{d\Delta\omega}{dt} = P_m - P_e - D\Delta\omega \quad (3)$$

$$\frac{d\delta}{dt} = 2\pi f\Delta\omega \quad (4)$$

Exciter model of "simplified model":

$$T_e\frac{dE_{fd}}{dt} = -E_{fd} + K_e(V_{ref} - V) \quad (5)$$

$$E_{fdmin} \leq E_{fd} \leq E_{fdmax} \quad (6)$$

PSS model of "simplified model": Equivalent mechanical damping constant

Load characteristics of "simplified model": ZIP type load model

TEPCO-BCU does not calculate CUEP of "simplified model" directly. TEPCO-BCU calculates CUEP of "reduced-state model" instead. It can be shown that, under certain conditions [12],[13], CUEPs of both models are associated. This fact can be proved mathematically [3].

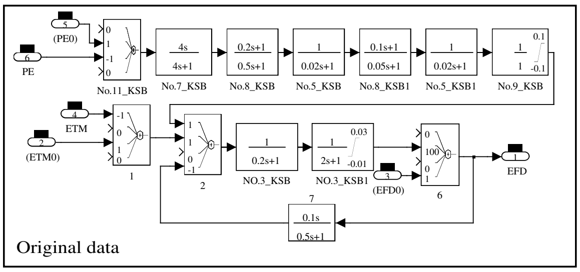

Figure 2: An Example of Detail Exciter Model

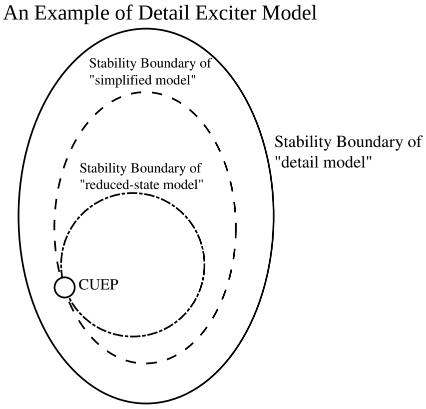

Figure 3: An Image of Stability Boundary of Each Model Type

The relationship among the stability boundary of each system model is described in Figure 3. The relation between the stability boundary of "simplified model" and that of "reduced-state model" can be proved mathematically. Although the relation between the stability boundary of "original model" and that of "simplified model" cannot be proved mathematically, it has however been confirmed by many numerical studies. It is easy to understand that transient stability would be conservatively affected when a simplified exciter model is applied to evaluate transient stability. In consequence, evaluation of transient stability might be conservative when a simplified exciter is used.

In this evaluation, the simulation results obtained by a detailed time-domain stability program on the "original model"are used as benchmark.TEPCO-BCU calculation results on the "simplified model" are compared with benchmark values. This evaluation of the relation of stability boundary between "original model" and that of "simplified model" is one important theme in this paper.

5 Numerical Studies

A project team is formed to evaluate the performance of TEPCO-BCU on practical power system data of large sizes such as a 12,000-bus system. The model system has 1,300 generators. There are two goals in this evaluation. One is to evaluate the accuracy of DSA of TEPCO-BCU and the other is to measure its computational speed. TEPCO-BCU has performed DSA of different sizes of power system data with satisfactory results.

A contingency consists of a single or multiple events defined at different times. For example, a contingency can be defined as a 3-phase fault with a specified fault-duration at the end of which the breakers open and the fault is cleared. The post-fault condition can be different from the pre-fault condition. Line, transformer and generator outages are considered in the contingency list in which multiple outages up to 16 items of equipment are allowed.

Table 1 shows that screening results of TEPCO-BCU under 199 contingencies of a 12,000-bus system. There is no unstable case among 184 cases classified by TEPCO-BCU as stable. Hence, TEPCO-BCU meets the requirement of efficiency measure of on-line dynamic contingency screening. Also, 15 cases are captured as (potentially) unstable by TEPCO-BCU. The ratio of unstable contingencies caught by TEPCO-BCU is 100% which shows that the reliability measure of dynamic contingency screening is met. It should be pointed out that of the contingency list, the number of contingencies requiring detailed time-domain analysis is reduced to 7.5% of the number of total contingencies.

Historically, energy margin has been used to provide a quantitative measure of the degree of system stability. Since energy margin is defined for a post-fault system and different contingencies lead to different post-fault systems, we felt that energy margin is not a direct quantitative measure. We propose the use of estimated CCTs as a direct measure of the degree of system stability.

TEPCO-BCU Results		Detail Simulation Results	
		No. Unstable	No. Stable
No. Stable	184	0	184
No. Unstable	15	2	13

Table 1: Screening Results of TEPCO-BCU

5.1 *Estimated CCT*

We hence compare the estimated CCTs by TEPCO-BCU with that by a detailed time-domain stability program. We use the notation CCT_B to denote the CCT calculated by TEPC-BCU on a simplified model and CCT_T by the detailed time-domain stability program on the "original model". Upper bound of CCT_T is set to be 0.2[sec]. The two computed CCTs associated with each contingency are plotted on the graph, which displays CCT_B on the horizontal axis and displays CCT_T on the vertical axis. In addition, the case calculated by the BCU-TDS method is denoted as $\triangle$ to distinguish with other cases whose CCTs are calculated by other modules within TEPCO-BCU. To be on the conservative side of stability assessment, the relationship CCT_B $<$ CCT_T must hold. It is clear that the solid line of Figure 4 indicates that CCT_B=CCT_T and all the plots have to be located at left-hand side of the solid line. As shown in the Figure, TEPCO-BCU satisfies the conservative relationship even on the set of very large power system data such as the 12,000-bus data. Again, this confirms the relation of stability boundary between "original model" and that of "simplified model".

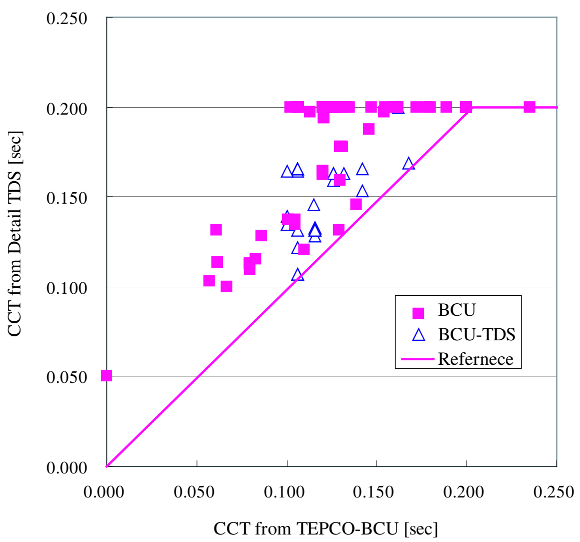

Figure 4: CCT_T vs. CCT_B

5.2 *Computational Speed*

TEPCO-BCU was performed on a computer with Pentium IV 2.7GHz. For a comparison purpose, the transient stability simulation program (variable time-step, VTS), developed by TEPCO, performs the detailed time-domain simulation for 10 [sec] of each contingency on the12,000-bus system for about 600 [sec]. We summarize the computation time needed by TEPCO-BCU and by VTS in Table 2. In the table, the average time, the maximum and minimum time needed for contingencies in the list are described for (improved) BCU classifiers, BCU-guided time-domain stability program and VTS.

	Average [sec]	Minimum [sec]	Maximum [sec]
BCU classifiers No. Cases = 163	11.6	0.01	49.5
BCU-TDS No. Cases = 36	49	29	68
VTS No. Cases = 199	6695	866	39000

Table 2: Elapse Time for TEPCO-BCU

We notice that although TEPCO-BCU achieves fast computation and high-degree accuracy, further improvement in computational speed is needed for TEPCO-BCU being applicable to on-line DSA of large-scale power systems such as a 12,000-bus power system.

It is also important to evaluate the scalability of TEPCO-BCU on different sizes of power systems. To find a relation between computation speed and system size, we apply TEPCO-BCU to a 3,000-bus power system data and summarize a comparison in Table 3. The elapse time increase 4.0 times as the number of buses increases by 4.0 times. It can be assumed that there is proportional relationship between elapse time and system size..

	Avarage Elapse Time[sec]
3,000-bus system	4.6
12,000-bus system	18.3

Table 3: System Size vs. Elapse Time

6 Data Converting Scheme

6.1 *Converting Exciter Model*

As mentioned in Sec.4, the model of excitation system needs to be simplified to a one-gain, one-time-constant model for TEPCO-BCU. We should notice here that the simplified model must yield conservative results than original model; otherwise, some unstable cases may be overlooked.

In the derivation of the simplified excitation model, we observe the frequency response of original excitation system, and then develop a simple first-order lag model. Although it is possible to apply a least-square method in the observed range to derive the simple model, it can cause overestimation of the contribution of excitation system to transient stability. In our experience, we can avoid such a problem by setting conditions leading the cut-off frequency of simplified model accords with the frequency of original model. Figure 5 shows the frequency response of both models.

Simplified exciter modeled by proposed method usually satisfy screening objective. However, the authors have few cases that energy margin of a contingency located near terminal of generator implemented thyristor-type AVR model might be not conservative. In above case, contribution of exciter for transient stability would be evaluated as too large by simplified exciter model. Therefore, it is necessary to consider a special measure treating thyristor-type AVR and we are studying now.

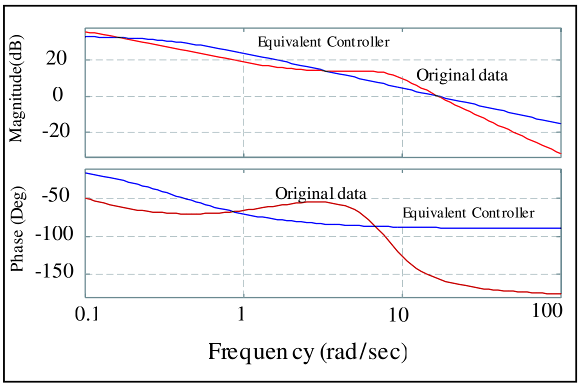

Figure 5: Frequency response of PSS

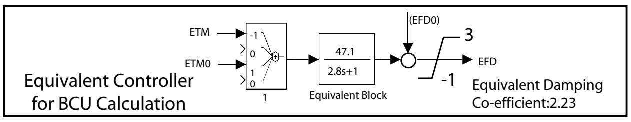

Figure 6: Simplified Exciter model with PSS

6.2 *Equivalent Damping of PSS*

It is well known that high-response exciter without PSS is inclined to reduce synchronizing torque. Hence, for a power system with many PSSs such as the ones in Japan, neglecting the effects of PSSs can cause excessively unstable estimation. This aspect is not desirable for dynamic contingency screening. So we use the equivalent damping torque coefficient to represent the effects of PSSs and this is obtained via the original exciter and PSS model.

To validate the effectiveness of equivalent damping of PSS, TEPCO power system (3,000-bus 200-generator system) was used because almost generators in this system have PSS to maintain angular stability. When all of equivalent damping of PSS are not modeled, TEPCO-BCU result become too conservative and unpractical. Also, any overestimation case does not exist.

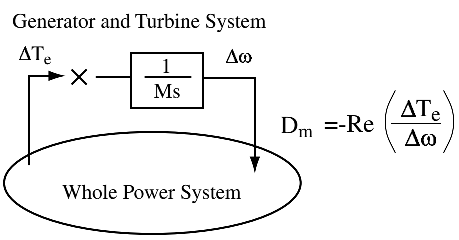

Figure 7: Equivalent damping torque

7 Integrated Data-handling

The capability of integrated data-handling is important. It is known that each analysis tool is developed for its primary purpose and it is usually of little use for other applications. For instance, TEPCO-BCU is valuable for DSA; however, it is not useful for small-signal stability analysis. Thus it is necessary to apply different analysis tools for multiple evaluations so as to provide measures against various risks. To satisfy these requirements, TEPCO has developed an analysis environment which is consisted of GUI, database, and script functions which are briefly introduced below.

Just for reference, an seletcted eigen-values of the 12,000-bus system can be solved within 2[sec] by an eigen-analysis tool "LINEAR" developed by TEPCO.

7.1 *GUI*

All the power system data are input via a GUI. We can build system data by using a mouse and ten-key. We can also use the GUI to run analysis applications and display the analysis results. One does not need to know complicated data format required in analysis tools.

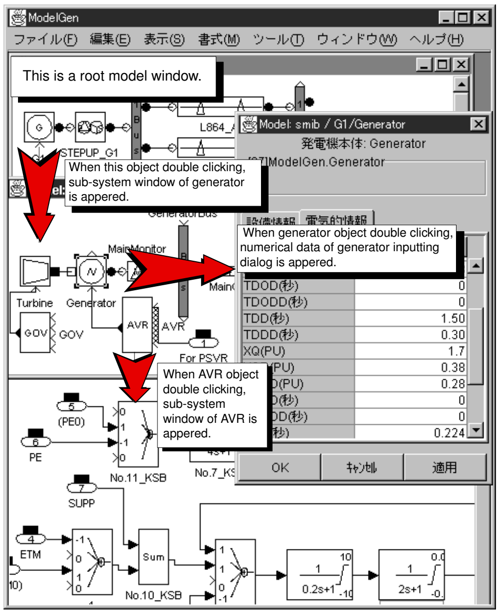

Figure 8: ModelGen Library

7.2 *Database*

All the data are stored in the database, which is compatible with TCP/IP networking so that users can share the data through a LAN or the Internet.

The data in the database is stored independent of any single application. The database internally converts data for an application before returning the queried data to the application. Thus, all applications in this environment can be run using common data. This is necessary for multidirectional analysis that is important to capture the characteristics of a power system.

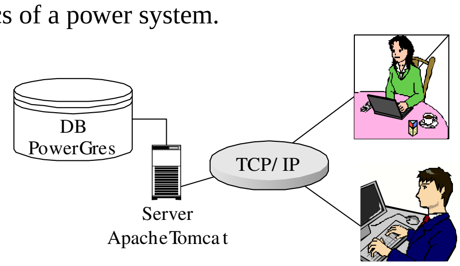

Figure 9: Network configuration

7.3 *Script function*

The script function allows a list of commands to be created, such as an analysis procedure. The script can then be executed without user interaction. Any analytical process such as "get some system data from the database", "change parameters", "run application", or "save result" can be written in script. It also allows control statement such as “IF THEN” or “FOR LOOP”. So repetitive analysis and routine tasks can be automatically executed.

By using the script function analysis labor is greatly reduced, especially when processing a huge case study, a task that is almost impossible to do manually.

7.3.1 *Combination of BCU and OPF performing Security Constrained OPF (SCOPF)*

We can estimate dynamic stability in a short time by use of the TEPCO-BCU system. However, an operator may prefer not only the stability assessment but also a solution to the instability. In order to provide the solution, we introduce an OPF algorithm, which is realized via applying the TEPCO-BCU engine. We ensure this algorithm can be written in Script.

In general, economic dispatch problem without dynamic stability is expressed as follows.

$$\min_{P_G} \quad f(P_G) \tag{7}$$

$$f(P_G) = \sum_{i=1}^{n_G} (\alpha_i {P_{Gi}}^2 + \beta_i P_{Gi} + \gamma_i) \tag{8}$$

$$\text{s.t.} \quad g(x, P_G) = 0 \tag{9}$$

$$h(x, P_G) \leq 0 \tag{10}$$

here,

n_G : number of generator
P_{Gi} : i^{th} generator output
x : general parameters other than P_G

Objective function is minimization of fuel cost. Equation (9) is power flow equations of all node’s active power and reactive power. (10) is general constraints for OPF such as the upper and lower limit of voltage or generator outputs. Generations are considered as parameter fixed to satisfy dynamic stability constraint.

To formulate dynamic stability constraint, we define energy margin sensitivity as a function of energy margin E_m.

$$\frac{\partial E_m}{\partial P_{Gi}} \tag{11}$$

This sensitivity is calculated by TEPCO-BCU. Then the stability constraint is expressed as follows.

$$E_m + \sum_{i=1}^{n_G} \left(\frac{\partial E_m}{\partial P_{Gi}} \Delta P_{Gi} \right) \geq E_t \tag{12}$$

E_t : Threshold value for energy margin

Applying Lagrangian relaxation to them, objective function is rewritten as follows:

$$\min_{P_G} \quad f(P_G) + \omega \left[E_t - E_m - \sum_{i=1}^{n_G} \left(\frac{\partial E_m}{\partial P_{Gi}} \Delta P_{Gi} \right) \right] \tag{13}$$

ω : weight coefficient

This problem is solved if weight coefficient ω is determined. For the purpose, following problem is introduced.

$$\min_{\Delta P_G} \quad f(P_{G_0} + \Delta P_G) \tag{14}$$

$$\text{s.t.} \quad \sum_{i=1}^{n_G} \Delta P_{Gi} = 0 \tag{15}$$

$$E_t - E_{m_j} + \sum_{i=1}^{n_G} \left(\frac{\partial E_{m_j}}{\partial P_{Gi}} \Delta P_{Gi} \right) \leq 0 \tag{16}$$

here,

P_{G_0} : initial generator output
ΔP_{G_i} : difference from P_{G_0} for i^{th} generator
E_{m_j} : energy margin for j^{th} contingency

To solve the above problem, dual variable λ_j for constraint (16) is obtained. Since λ_j means sensitivity of cost to energy margin, sensitivity of cost to generator output is calculated as follows.

$$\lambda_j \frac{\partial E_{m_j}}{\partial P_{Gi}} \tag{17}$$

Then we can see that dynamic stability constraint can be considered as long as cost coefficient β is modified.

$$\beta_i' = \beta_i + \sum_{j=1}^{n_C} \left(\lambda_j \frac{\partial E_{m_j}}{\partial P_{Gi}} \right) \tag{18}$$

n_C : number of contingencies

Consequently, SCOPF can be performed using β' in plase of β in (7) $\sim$ (10).

As described above, this SCOPF algorithm considering dynamic stability is shown as Figure 10. By use of script function, this algorithm can be easily realized.

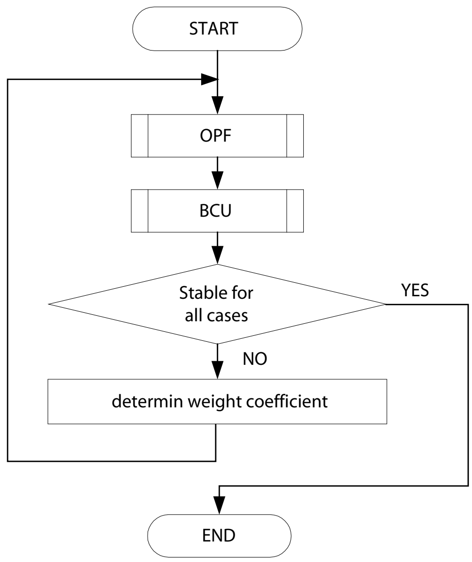

Figure 10: OPF algorithm considering dynamic stability

We applied the SCOPF to a sample system shown in Figure 11. (Acceptable Energy margin: 0.2, Maximum iteration: 10, initial cost coefficient β: (G1,G3)100.0, (G2,G4)110.0)

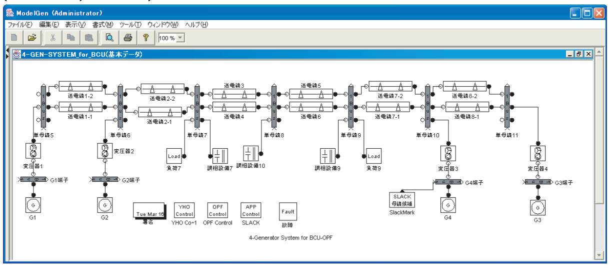

Figure 11: test system

Feasible solution was found in 3rd iteration. Figure 12 indicates the objective function value (fuel cost) and energy margin to the iteration. The values on 1st iteration means a solution without dynamic security constraint. We can see that increase of energy margin involves a growth of fuel cost. The additional cost can be explained by satisfying dynamic security.

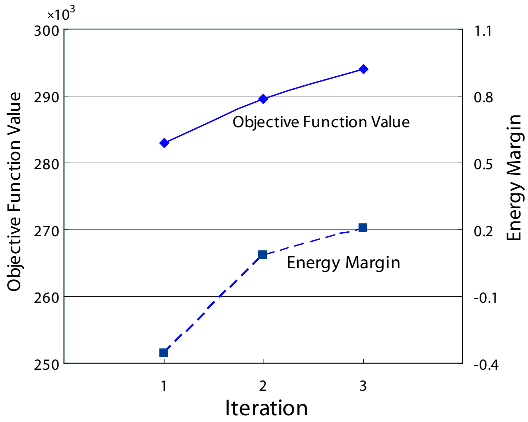

Figure 12: objective function value (fuel cost) and energy margin

The point is that operator can obtain a solution even for dynamic instable case as long as SCOPF is applied. It is more important that this kind of highly advanced function can be realized by the combination of powerful analysis tool and analysis environment.

8 Future Works

As mentioned above, the current version of TEPCO-BCU has enough capability to meet DSA specifications, although there are many issues for enhancing availability. For example, the improvement themes are following.

- To implement HVDC and FACTS model
- Addition of available contingency type (c.f. single line grounding fault)

9 Conclusions

TEPCO-BCU is a transient stability evaluation program designed for large-scale power systems. TEPCO-BCU is composed of several computation modules such as improved BCU classifiers, BCU method, BCU-guided time-domain method and a fast time-domain simulation program. Current version of TEPCO-BCU is able to perform exact stability assessment and accurate energy margin computation of each contingency of large-scale power systems.

In this paper, the feasibility of applying TEPCO-BCU to a 12,000-bus power system data is investigated. This paper reports some experiments of this feasibility study in which the energy margins and estimated CCTs of all contingency cases are accurately determined. In current version of TEPCO-BCU, the excitation model of each generator has to be simplified into a one-gain-one-time-constant model. This paper presents a method to reduce a comprehensive excitation system model including PSS into the simplified one. A frequency-domain method is developed to calculate equivalent coefficient of damping factor of PSS. The accuracy of TEPCO-BCU is then confirmed on the 12,000-bus power system data by comparing its results, in which a simplified excitation system is used with the results obtained by a time-domain transient stability simulation program on a detailed excitation system model.

This paper points out that appropriate data handling is also important. Data converting technique to create simplified excitation system data from a detailed model is not difficult, but a complicate task so that sophisticated data handling is desired. We feel that IMPACT developed by TEPCO is a preferable power system data handling software environment.

Furthermore, this paper discuss the possibility of developing control schemes to enhance transient stability by combining TEPCO-BCU program and OPF. Practical application of the proposed development will be reported by the authors in the near future.

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