AN EFFICIENT CONTINGENCY SCREENING SCHEME FOR ATC ASSESSMENT WITH TRANSIENT STABILITY CONSTRAINTS

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Abstract – Under deregulated environment, it is essential to accurately and efficiently evaluate available transfer capability (ATC) for the effective use of transmission network. The consideration of dynamic security constraints is crucial for the successful application of ATC assessment to stability-constrained networks. As evaluation of dynamic stability requires large computational burden, an efficient contingency screening method is necessary. In this paper, a novel approach of pre-screening of contingency is proposed, which is suitable for ATC assessment with transient stability constraints. The proposed method utilizes a hybrid approach, which takes advantages of both energy function method and eigenvalue analysis. The proposed method can identify severest faults in maximum loading scenario in prior to the iterative process of ATC assessment with respect to supply/demand scenarios, so that large speed-up can be obtained by the application of the proposed method.

Keywords: ATC, dynamic security assessment, contingency screening, energy function method, eigenvalue analysis

1 INTRODUCTION

It is one of the big issues to use network effectively in the competitive environment. Accurate assessment of ATC is one of key techniques to make more effective use of network. In some countries and areas, ATC assessment is already in operation. However the constraints of dynamic stability (first-swing stability, as well as multi-swing stability) is simplified, or even omitted in assessment procedures. Assessment of dynamic stability by time-domain simulation method requires much computational time, so that incorporation of dynamic security assessment (DSA) procedure is not practical.

The consideration of stability constraints in ATC assessment is crucial for the successful application of ATC assessment to stability-constrained networks. One of the approaches to make speed-up of assessment of ATC with dynamic stability constraints (stability ATC) is the application of contingency screening technique.

A number of contingency screening methods have already proposed [1-7] and the authors have proposed pre-screening method of contingency [8]. The idea of this pre-screening method is to identify the severest contingencies in maximum loading scenario in prior to the iterative process of ATC assessment with respect to supply/demand scenarios. This approach has advantage that the procedure should be processed only once in whole ATC assessment procedure. In [9], a combinational use of energy function method and eigenvalue analysis is applied to this pre-screening method.

In this paper, the approach in [9] is further improved to obtain more accuracy in identification of severe faults with respect to first swing stability as well as multi-swing stability. The accuracy is examined by an extensive study using model power systems, which represents dynamic characteristics of Japanese interconnected power systems. The numerical examples also show the effectiveness of the proposed method to speed-up overall process of stability ATC assessment.

2 PRE- SCREENING OF CONTINGENCY BASED ON ENERGY FUNCTION METHOD AND EIGENVALUE ANALYSIS

2.1 Pre-screening of contingency for fast ATC assessment

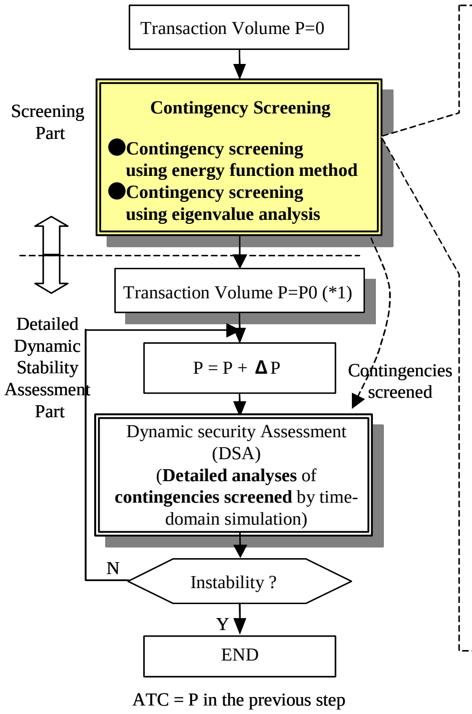
As shown in Figure 1, the idea of pre-screening is to identify severest faults in maximum loading scenario in prior to the iterative process of ATC assessment.

For this purpose, it is important to take into account the impact of transaction to be studied. Because power flow changes in ATC assessment result from increase of transaction volume, contingencies whose severity is largely affected by introduction of transaction should be closely examined in DSA process.

In the contingency screening process, two screening indices are utilized to identify this kind of contingency. One contingency index *SEF* is based on energy function method and the other index *SEV* is based on eigenvalue analysis. The sum of two groups of contingency chosen by *SEF* and *SEV* respectively are identified as the severe contingencies, which are to be investigated in iterative process of ATC assessment.

2.2 Contingency screening based on energy function approach

An energy function method based contingency severity index *SEF* is given by the following equation:



Screening Indices

Index	Cases to be screened	Method of screening
SEF	Mainly, cases with first-swing instability	･Based on energy function method ･Apply longer fault clearing time (e.g. 0.2[sec]) than usual to emphasis the severity of contingency ･Identify contingencies as "severe", where system is unstable just after fault is cleared ･Supply/demand scenarios, where detailed analysis is required, are identified based on the change in number of "severe" faults as transaction volume increases
SEV	Mainly, cases with multi-swing instability	･Based on eigenvalue analysis ･Utilize the sensitivities of the following quantities with respect to transaction volume 1) Damping of swing modes 2) Participation factors of the generator, which is "source" of transaction, with respect to swing modes ･Identify a given number of contingencies as "severe", which have largest sensitivities

(*1) P0 is transaction volume in supply/demand scenario for screening

Figure 1: The proposed ATC assessment procedure and contingency screening method

$$SEF = {}^{V_P}\!\big/_{V_K} \qquad (1)$$

where V_P is the difference between maximum potential energy before a fault is cleared and the potential energy at the corresponding exit point. V_K is kinetic energy. Severity index SEF represents a stability margin with regard to a contingency.

In this paper, contingencies are categorized depending on when the system passes "exit point" after a fault is imposed as shown in Figure 2. If the system passes exit point before fault is cleared, V_P becomes 0. This type of instability is referred as "type-1 instability" here. If the system passes exit point after fault is cleared, V_P becomes more than 0. This type of instability is referred as "type-2 instability" in this paper. It can be said that, in case of contingency of type-1 instability, the system approaches to boundary of stability region faster compared to in the case of contingency of type-2 instability.

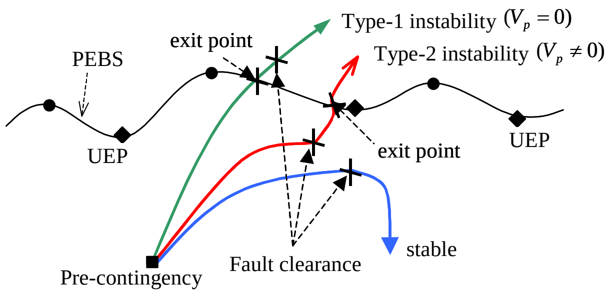


Figure 2: Type-1 and type-2 instability

In other words, contingencies of type-1 instability are more severe than contingencies of type-2 instability. Consequently, type-1 instable contingencies have to be investigated in dynamic security assessment.

If power system is not heavily stressed, namely, when fault is cleared with usual fault clearing time, no contingency is type-1 instable. To take advantage of the above categorization, it is assumed that a fault is cleared in much longer clearing time. Consider that fault clearing time is 0.3[sec.]. In this case, any fault with critical clearing time less than 0.3[sec.] results instability, and some of them may be type-1 instable. Generally speaking, imposing long clearing time emphasizes severity of each fault, so that faults with type-1 instability are expected to be severest faults.

Based on the above discussion, contingencies with type-1 instability are investigated in contingency analysis of stability ATC assessment in this paper.

2.3 Selection of supply/demand scenario for screening

It should be noted that power flow in maximum loading scenario may quite different from power flow of base case supply/demand scenario (base power flow). For example, if transaction power flow is "counter flow" to base power flow, contingency screening by the above procedure utilizing base case supply/demand scenario may not be accurate. Therefore, a suitable scenario should be chosen, so that the contingency screening procedure can accurately evaluate the impact of transaction on contingency severity. In this paper, this scenario (supply/demand scenario for screening) is selected using the number of type-1 contingency by the following iterative process.

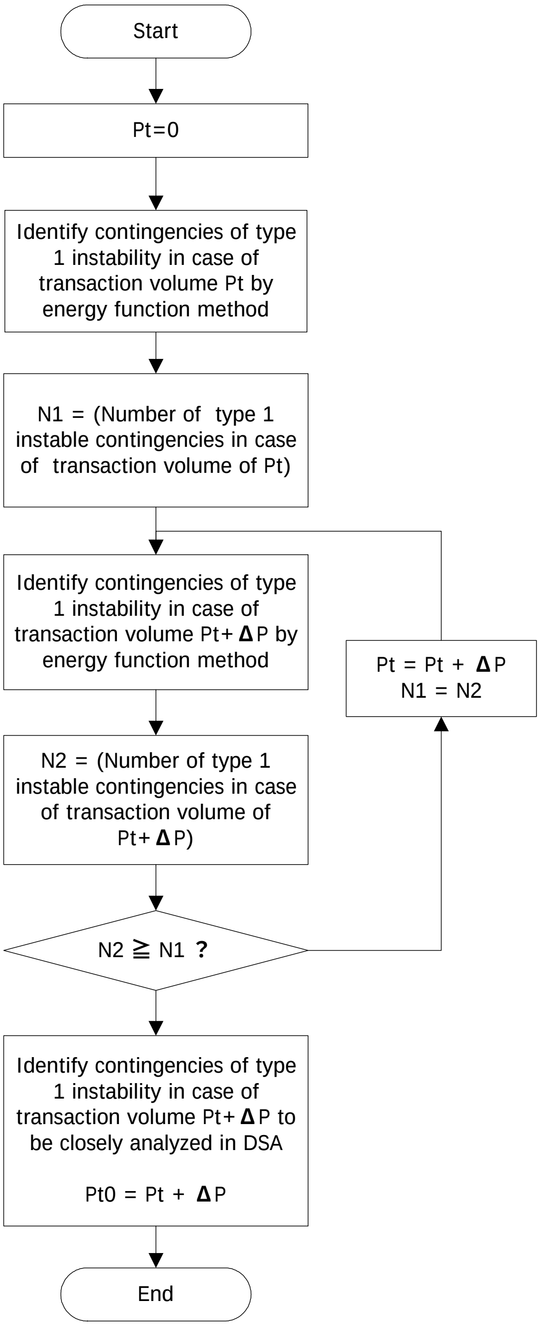


Figure 3: Contingency screening procedure using energy function method

First, the group of type-1 instable contingency in a supply/demand scenario with transaction volume P_t is identified. Then, the corresponding group in another scenario with transaction volume $P_t + \Delta P$ is also identified. If these two groups are identical, or, if the latter group is smaller, P_t is updated to be $P_t + \Delta P$ and identification of the groups is made again. This iteration will be continued until type-1 instable contingency group in the scenario with transaction volume $P_t + \Delta P$ is bigger than the group in the scenario with transaction volume P_t. When the iteration process is terminated, the scenario with transaction volume $P_t + \Delta P$ is chosen as the scenario for the screening.

2.4 Contingency screening based on eigenvalue analysis

Contingency screening based on energy function method has sometimes difficulty in identification of severe faults with multi-swing instability [8]. Therefore, it is better to utilize supplemental information to energy function based contingency screening to make more accurate contingency screening. In this paper, supplemental contingency severity index based on eigenvalue analysis is used.

The following two indices *SEV1* and *SEV2* are utilized:

1) Sensitivity of damping of power swing modes

$$SEV1_{ij} = \Delta\lambda_{Rij} = \mathrm{Re}(\lambda_{ij})\Big|_{P_t+\Delta P} - \mathrm{Re}(\lambda_{ij})\Big|_{P_t} \tag{2}$$

2) Sensitivity of participation factor of the generator involved in the transaction under study

$$SEV2_{ij} = \Delta PF_{ij} = PF_{ijG_{NF}}\Big|_{P_t+\Delta P} - PF_{ijG_{NF}}\Big|_{P_t} \tag{3}$$

$$PF_{ijG_{NF}} = \frac{\left|v_{G_{NF}}\right|}{\sum_k \left|v_{ik}\right|} \tag{4}$$

where $\mathrm{Re}(\lambda_{ij})$ is the real part of *i*-th power swing mode while contingency branch *j* is opened. $PF_{ijG_{NF}}$ is the participation factor of the generator G_{NF}, which involved in the transaction under study, with respect to *i*-th power swing mode while contingency branch *j* is opened. v_{ik} is the *k*-th element of eigenvector of *i*-th power swing mode. $v_{G_{NF}}$ is the element of the eigenvector with respect to angle velocity of G_{NF}.

The indices *SEV1* and *SEV2* are sensitivities with respect to transaction volume. This means that these indices represent the impact of introduction of transaction to be studied and large *SEV* means that the contingency becomes more severe as the transaction volume increases. Consequently, contingencies with larger *SEV* are chosen and investigated in contingency analysis in stability ATC assessment.

3 NUMERICAL EXAMPLE

To show the effectiveness of the proposed screening procedure, IEEJ EAST30/WEST30 model power systems[10] are used here. Figures 5 and 6 show these model power systems and transactions assumed. Transactions E1 and W1 represent long distance transactions, while E2 and W2 represent short distance transactions. Transactions E3 and W3 represent transactions, which are “counter flow” to base, power flow.

3LG/3LO faults on each end of all transmission lines are considered in ATC assessment. Total number of contingency is 136 in IEEJ EAST30 system and 82 in IEEJ WEST30 system.

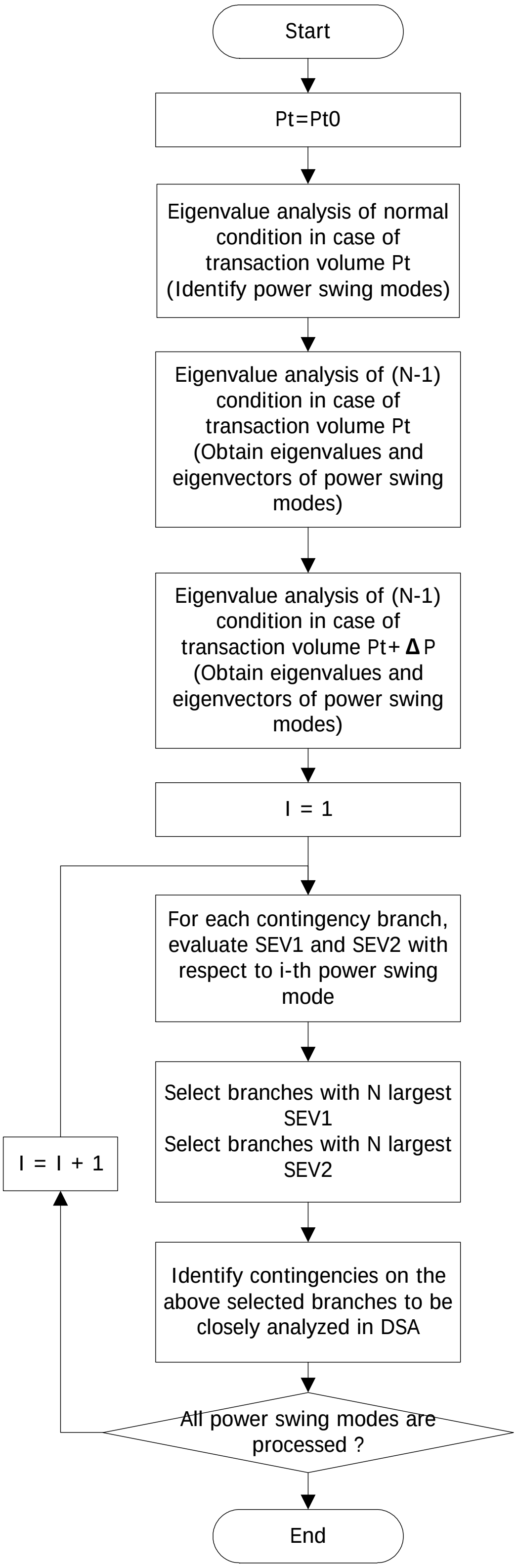


Figure 4: Contingency screening procedure using eigenvalue analysis

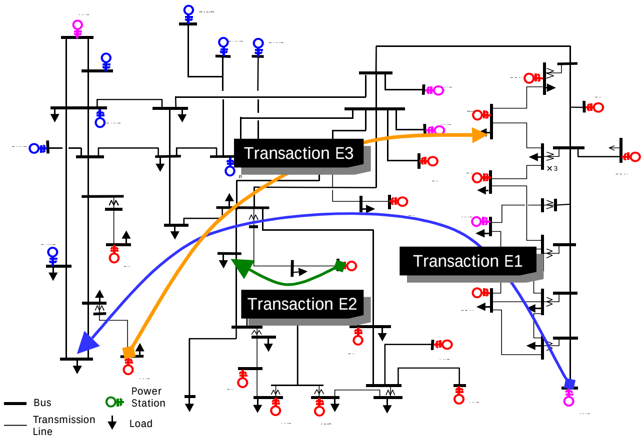


Figure 5: IEEJ EAST30 model power system

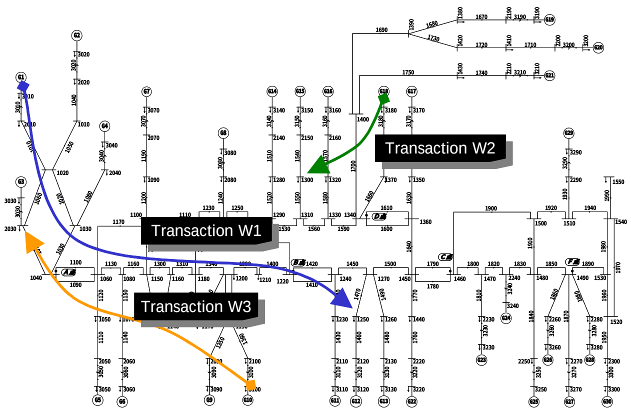


Figure 6: IEEJ WEST30 model power system

In pre-screening procedure, additional transaction volume ΔP is assumed to be 1000[MW]. In evaluation of *SEF*, it is assumed that the fault clearing time is 0.16[sec] in cases with EAST30 system and 0.20[sec] in cases with WEST30 system. The number of branches selected by *SEV1* and *SEV2* is assumed to be 4 (i.e. 8 contingencies) in all cases.

Table 1 shows the results of stability ATC assessment both with and without the proposed pre-screening scheme. The results show that accurate ATC is obtained with respect to all of 6 transactions by the proposed method. “Conventional method” represents the case without pre-screening, where all of contingencies are examined by time-domain simulation (20[sec.]) in contingency analysis of ATC assessment. In case of the proposed method, the numbers of contingencies closely examined in DSA are reduced to 1/5~1/10. Necessary computation time is also reduced to 1/2~1/4 by application of the proposed method.

Table 1: Results of stability ATC assessment

Model power system & Base case scenario	Transaction pattern	ATC [MW] (*1)	Type of instability	Conventional method (*2)		Proposed method			
				Number of contingencies in DSA	**Computation Time [Sec]**	Number of contingencies screened	**Computation Time [Sec]**	**Ratio to conventional method**	Index identifing the severest fault (*3)
EAST30, Peak	E1	340	First-swing	136	**390.2**	15	**222.4**	**0.57**	SEF, SEV
	E2	2030	Multi-swing	136	**880.4**	12	**211.3**	**0.24**	SEF
	E3	2600	First-swing	136	**944.7**	11	**274.0**	**0.29**	SEF, SEV
WEST30, Peak	W1	170	Multi-swing	80	**327.6**	12	**144.1**	**0.44**	SEF
	W2	3500	Multi-swing	80	**731.4**	16	**175.5**	**0.24**	SEF, SEV
	W3	2910	Multi-swing	80	**528.6**	12	**163.9**	**0.31**	SEV

*1…In all cases, ATC obtained by the proposed method is identical to ATC by conventional method.
*2…Conventional method doesn't utilize contingency screening and all contingencies are considered in DSA.
*3...SEF is based on energy function method, SEV is based on eigenvalue analysis.

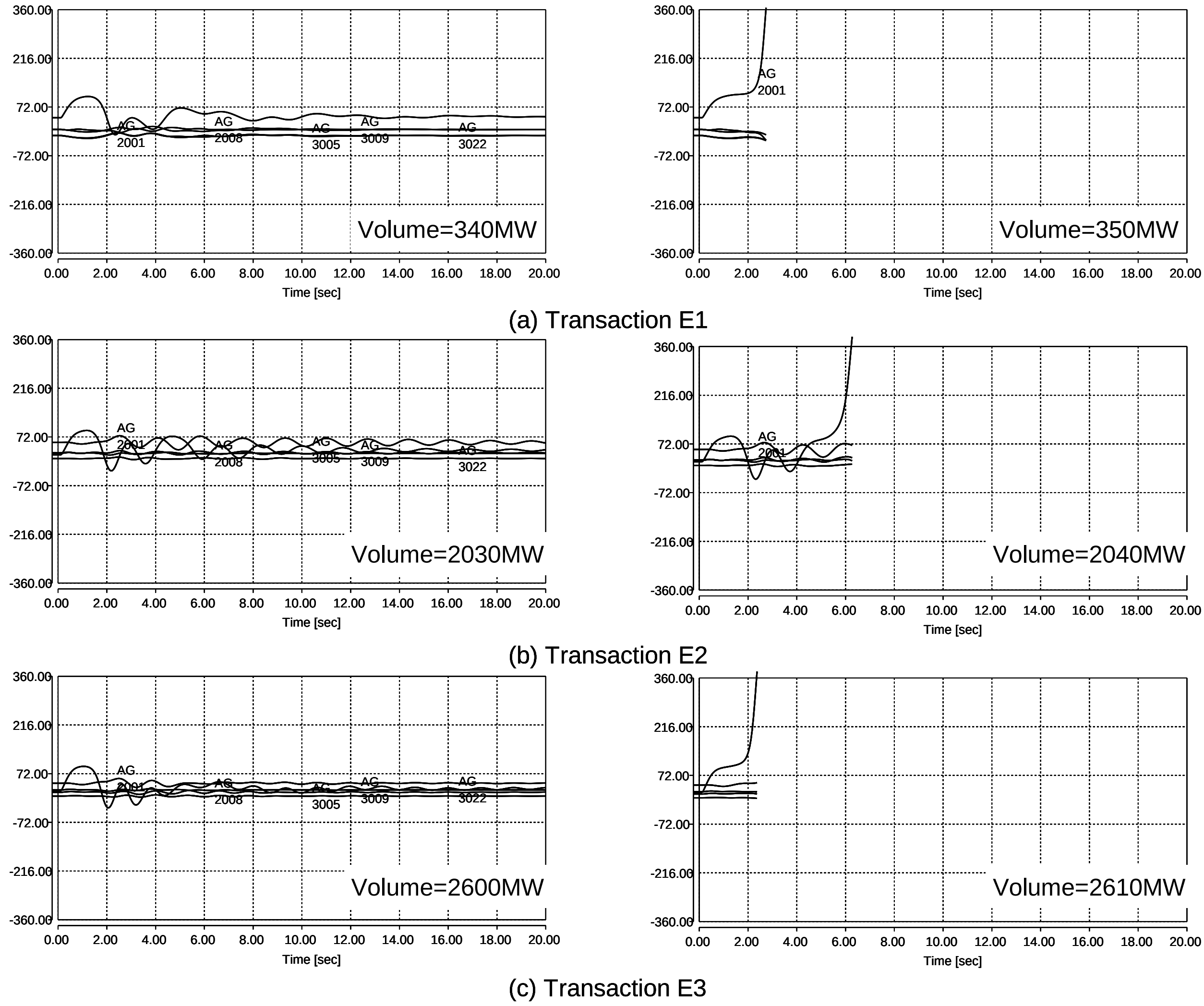


Figure 7: Swing curves after the severest contingency (EAST30 model system cases)

Also note that contingency severity index identifying the severest fault depends on transaction to be analyzed. Screening index *SEF* can identify the severest faults in maximum loading scenario corresponding to transactions E1, E2, E3, W1 and W2, while *SEV* identify the severest faults corresponding to E1, E3, W2 and W3. This means that the identifications by both screening indices are supplemental to each other. In other words, application of only one screening index is not enough and combinational use of screening indices has advantage of accurate identification of severest faults.

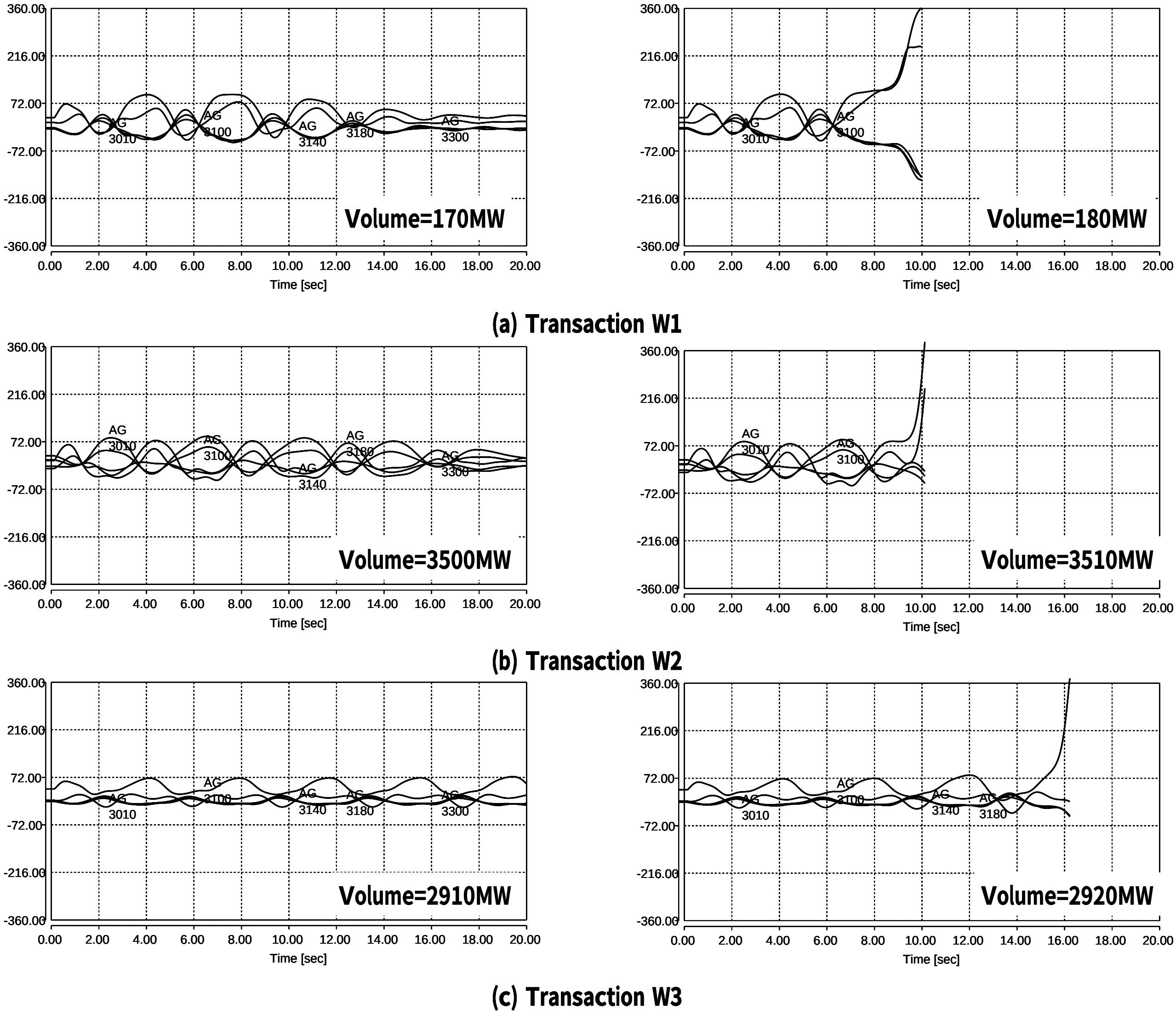


Figure 8: Swing curves after the severest contingency (WEST30 model system cases)

Table 2: Accuracy of the proposed contingency screening method

Model Power System	Base case Scenario	Number of transaction cases (*1) (number of cases with multi-swing instability)	Number of cases, where the proposed method identifies the severest faults	
			○	×
EAST30	Peak	84 (60)	84	0
	Night	84 (36)	84	0
WEST30	Peak	92 (82)	92	0
	Night	98 (94)	96	2
Total		358	356	2

*1...Number of cases among 100 cases (all combinations of 10 sources and 10 sinks), where dynamic stability constraints has limiting effect on transmission capability

Figures 7 and 8 show the swing curves after the severest contingency of each transaction cases. From these figures, it can be said that, even in cases where the behavior of system after the severest contingency is very complex, ATC can be accurately evaluated by the proposed method.

To clarify the accuracy of the contingency screening by the proposed method, an extensive study is made, where totally 400 transaction cases are examined using EAST30 and WEST30 model systems. Table 2 shows that in 356 cases among 358 cases, where the dynamic stability has limiting effect, the proposed method identify the severest contingency correctly. This shows that the proposed method has good performance from the viewpoint of accuracy of screening.

4 CONCLUSION

In this paper, a novel approach of pre-screening of contingency for fast ATC assessment with stability constraints is proposed. In this procedure, contingencies are selected for ATC assessment with transient stability constraints based on contingency severity indices using energy function method and eigenvalue analysis. Numerical example shows that the proposed procedure can identify severest fault in maximum loading scenario in prior to iterative process of ATC assessment, both in cases with first-swing instability and in cases with multi-swing instability. The example also shows that two contingency severity indices are supplemental to each other and their combinational use is effective to identify severest contingency accurately. As this screening procedure should be processed only once in prior to iterative process, it can contribute to the speed-up of whole ATC assessment procedure.

Numerical examples in this paper are limited to point-to-point ATC evaluation, and applicability of the proposed method to area-to-area ATC assessment will be examined.

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