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A Novel SIME Configuration Scheme Correlating Generator Tripping for Transient Stability Assessment

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Abstract – When a contingency occurs in a large transmission route in a power system, it can generate various instabilities that may lead to a power system blackout. In particular, transient instability in a power system needs to be immediately addressed, and preventive measures should be in place prior to fault occurrence. Measures to achieve transient stability include system reinforcement, power generation restriction, and generator tripping. Because the interpretation of transient stability is a time domain simulation, it is difficult to determine the efficacy of proposed countermeasures using only simple simulation results. Therefore, several methods to quantify transient stability have been introduced. Among them, the single machine equivalent (SIME) method based on the equal area criterion (EAC) can quantify the degree of instability by calculating the residual acceleration energy of a generator. However, method for generator tripping effect evaluation does not have been established. In this study, we propose a method to evaluate the effect of generator tripping on transient stability that is based on the SIME method. For this purpose, the measures that reflect generator tripping in the SIME calculation are reviewed. Simulation results obtained by applying the proposed method to the IEEE 39-bus system and KEPCO system are then presented.

Keywords: SIME method, Transient stability assessment, Transient stability margin, Generator tripping, Power system stability.

1. Introduction

The complexity of power systems progressively increases with increasing load. Power plants are becoming larger, and the reinforcement of transmission facilities is becoming increasingly difficult owing to social factors. As a result, increasingly large amounts of power are transmitted via a small number of transmission routes. This situation leads to problems related to system stability. Recent power outages, have shown that the stability problem of the power system instability increases the possibility of a power outage [1].

Korean power systems are experiencing similar challenges. In the case of the Korean power system, there is a large imbalance between load and generation by region. Most of the load is concentrated in the capital area, and large-scale generators are concentrated in non-capital areas [3]. In particular, large-scale power plants are located in the west and east coastal areas. In order to prevent transient instability on the east and west coastal areas, the SPS is installed that trip the generators when the contingency occurs. Although there are already large-scale power generation facilities in these areas, additional generation facilities will be installed that areas by the plan [2]. Therefore, the problem of transient instability in the east and west coast areas will become more severe in the future. Recently, expanding the supply of renewable energy in Korea has been discussed [4]. However, the new renewable energy sources are planned to be centralized in regions other than the capital area where the loads are concentrated. Thus, it is expected that the supply of renewable distributed power sources will not resolve the large power transmission problem of the capital area [5-7].

The quantification of transient stability is currently being researched. The easiest method that can be applied implements critical clearing time (CCT) [8]. This method can quantify the transient stability level through repeated calculations. However, repetitive analysis is necessary to accurately determine the CCT value. Therefore, the CCT is only used to measure the transient stability level. A general method for measuring transient stability is the equal area criterion, which calculates the acceleration/deceleration energies of a generator by reflecting a contingency in the power-angle curve [8]. This method can intuitively measure the transient stability level, but it is not easy to practically implement this method unless the system is a single-machine-two-bus system. In an actual system, which has multiple interconnected generators and complex mashed transmission lines, it is difficult to construct a power-angle curve. To overcome this limitation, a method of converting the entire system to a one-machine-infinite-bus (OMIB)

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form has been proposed [9-11]. The proposed method is to configure an equivalent generator, referred to as a single machine equivalent (SIME) generator, by classifying generators as stable or unstable. This analysis can create a power-angle curve for contingencies, and the system can thus be analyzed using the equal area criterion. The transient stability evaluation technique using the SIME method is used in a variety of fields owing to its convenience of application and use. The SIME method is most commonly implemented in the analysis of transient stability.

A general system control method to achieve transient stability is the constrained generation of critical generators [9-12]. Existing studies have proposed various SIME-based methods to restrict power generation. Generally, SIME analysis can identify transient stability faster than manual analysis. FILTRA has been proposed as a way to utilize it and is used in determination of on-line stability [9, 11]. Application of the SIME methods to the Italian power system has been studied. This study proposes an on-line transient stability evaluation and stabilization method [14]. A SIME-based method is also applied to determine the re-closing time of the transmission line. When the transmission line is interrupted owing to fault detection, reclosing is performed to check whether the fault has been erroneously detected. If it is an actual failure, the fault reappears and the transient stability problem reoccurs. To prevent transient instability after re-closing, previous studies have proposed a method to determine the re-close timing by using the SIME method [15, 16]. Another application in which the SIME method is used is transient stability-constrained optimal power flow (TSCOPF). In general, the OPF is performed in the steady-state domain, thereby making it very difficult to consider the transient stability constraint. To overcome this limitation, the SIME-based transient stability method is used. In TSCOPF systems, the SIME method is used as a transient stability constraint. The most widely used technique entails setting the stability constraint on the phase angle or stability margin via SIME analysis [17-19]. In later studies, sensitivity analysis has been used to minimize constraint generation for stabilization when determining stability constraints [20, 21]. The insights provided by recent studies have been applied to determine the transient stability constraints in robust optimization or large wind farms [22, 23].

In this study, the effects of generator tripping on SIME are examined, and a calculation method that accurately considers generator tripping in SIME is proposed. In addition, a method to quantify the effects, and a way to implement this method to evaluate transient stability, is proposed. Two methods that can be generally considered to accurately consider generator tripping in SIME are described and examined. Then, the characteristics of each method are derived and a method to quantify the effects of generator tripping is suggested. The feasibility of evaluating the transient stability effects via the proposed method is confirmed via simulation of the IEEE 39-bus and KEPCO system by using the proposed method.

2. Conventional SIME Method

2.1 Equal area criterion and SIME method

The equal area criterion is a general method to evaluate the transient stability of a system [8]. Fig. 1 shows the P-δ curve of a generator. When a contingency occurs, the electrical output of the generator decreases owing to a voltage drop, and the generator is accelerated as a result. After fault removal, the generator decelerates because the electrical output increases subsequent to the fault-induced phase angle increase. However, after contingency, the transmission line is removed; this lowers the height of the power-angle curve. If the acceleration area, which is the integral of acceleration energy, is larger than the deceleration area, which is the integral of deceleration energy, the generator accelerates again and is desynchronized.

The energy function method and the hybrid method are used to analyze the transient stability in the form of acceleration energy and deceleration energy. In the case of the energy function method, once the energy function is calculated, stability instability and the level of stability can be determined only by the magnitude of the acceleration energy. However, it is not easy to calculate the energy function, and if the system topology changes, the energy function had to recalculate. On the other hand, Hybrid method is based on time domain simulation. Therefore, topology and dynamic model are reflected in the time domain simulation result. If the case changes, the transient stability level must be recalculated through the simulation results, but the transient stability level can be easily evaluated compared to the energy function method.

In order to analyze transient stability via the hybrid method, the system should be contracted to an OMIB system [9]. For this contraction, all generators in the system are classified as either stable or unstable, and are

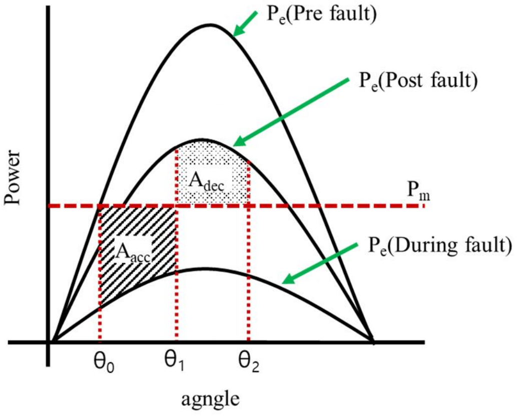

Fig. 1. Characteristics of P- δ curve in the contingency

then equated. The equivalent phase angles of these two groups are defined in terms of their center of angle (COA). The definition COA of each groups and the equivalent rotor angle δ is given as follows:

$$\begin{cases} \delta_C \triangleq M_C^{-1}\sum_{i\in C} M_i\delta_i \\ \delta_N \triangleq M_N^{-1}\sum_{k\in N} M_k\delta_k \end{cases} \tag{1}$$

where,

$$(M_C = \textstyle\sum_{i\in C} M_i \ , \ M_N = \sum_{k\in N} M_k) \tag{2}$$

$$\delta \triangleq \delta_C - \delta_N \tag{3}$$

where δ_i is the angle of machine i, and M_i is the inertia of machine i. Subscript C and N denote the critical and non-critical groups, respectively. The angular velocity and angular acceleration of each equivalent generator can be calculated as based on the above definition.

$$\begin{cases} \omega_C = \dot{\delta}_C = M_C^{-1}\sum_{i\in C} M_i\omega_i \\ \omega_N = \dot{\delta}_N = M_N^{-1}\sum_{k\in N} M_i\omega_k \end{cases} \tag{4}$$

$$\begin{cases} \ddot{\delta}_C = M_C^{-1}\sum_{i\in C} M_i\ddot{\delta}_i \\ \ddot{\delta}_N = M_N^{-1}\sum_{k\in N} M_i\ddot{\delta}_i \end{cases} \tag{5}$$

$$\omega = \omega_C - \omega_N \tag{6}$$

$$\ddot{\delta} = \ddot{\delta}_C - \ddot{\delta}_N \tag{7}$$

Based on the angular acceleration formula, the mechanical/electrical outputs of the equivalent generator can be calculated as follows:

$$P_m = M(M_C^{-1}\textstyle\sum_{i\in C} P_{mi} - M_N^{-1}\sum_{k\in N} P_{mk}) \tag{8}$$

$$P_e = M(M_C^{-1}\textstyle\sum_{i\in C} P_{ei} - M_N^{-1}\sum_{k\in N} P_{ek}) \tag{9}$$

$$(M = M_C M_N/(M_C + M_N)) \tag{10}$$

and P_{mi} is the mechanical output of machine i; Pei is the electrical output of machine i. The equivalent generator can be constructed and the transient stability of the system can be determined via the above method. The transient stability is calculated in consideration of the equal area criterion. The transient stability margin η is calculated as follows:

$$\eta = A_{dec} - A_{acc} \tag{11}$$

The transient stability margin can also be calculated also via the angular velocity of the equivalent generator, as follows:

$$\eta = \int_{\theta_0}^{\theta_2} P_m - P_e d\delta = \tfrac{1}{2}M\omega^2 \tag{12}$$

2.2 Generation tripping in emergency control

In the conventional method, generator tripping is proposed as a method for emergency control [9]. Strictly, the existing method is not a method to analyze the effects of blocking the generator. However, there is no suggestion to reflect the generator tripping in SIME. Generator tripping and assessment method in emergency control is the closest measure to the proposed method. The purpose of the method is to detect the transient instability of the generator and trip the generator. Therefore, this method requires various assumptions.

Assuming that the system data is acquired in regular time intervals, the magnitude of the acceleration energy can be estimated as based on the data. Although the estimation can be made up of various functions, a quadratic function is utilized in this chapter. The acceleration energy function obtained from the previous data at a specific time is composed as follows:

$$P_a(\delta) = a\delta^2 + b\delta + c \tag{13}$$

With Eq. (13), we can derive a P-δ curve and determine the transient stability of the system. If transient instability is detected, a generator trip is executed. If the generator is tripped, the SIME is configured exclusive of the disconnected generator. The new acceleration energy function is constructed as follows to reflect the generator trip:

$$P_a^{(1)} = a^{(1)}\delta^2 + b^{(1)}\delta + c^{(1)} \tag{14}$$

Superscript (1) means that the value is restructured exclusive of the generator that is to be cut off, that only the tripping signal is generated, and that the generator is not blocked. Eq. (15) denotes the relationship between the time taken to trip the generator T_{trip} (i.e., the delay time) and the phase angle at the time that the generator is tripped. The phase angle $\delta_{trip}^{(1)}$ occurring at the generator tripping time should be obtained via numerical calculation.

$$T_{trip} = \int_{\delta_i}^{\delta_{trip}^{(1)}} \frac{d\delta^{(1)}}{\sqrt{\frac{2}{M}\int_{\delta_i^{(1)}}^{\delta^{(1)}} -P_a^{(1)} d\delta^{(1)} + \left(\omega_i^{(2)}\right)^2}} \tag{15}$$

$$\begin{aligned} A_{acc.trip}^{(1)} &= -\frac{1}{2}M^{(1)}\omega_{trip}^{(1)}{}^2 \\ &= -\int_{\delta_i^{(1)}}^{\delta_{trip}^{(1)}} P_a^{(1)} d\delta^{(1)} - \tfrac{1}{2}M^{(1)}\omega_i^{(1)}{}^2 \end{aligned} \tag{16}$$

Finally, we have constructed the acceleration energy function subsequent to generator tripping. It is assumed that the electrical power output is unchanged after generator tripping. The acceleration energy function following a generator trip under the assumption and transient stability margin is as follows:

$$P_a^{(2)} = P_a^{(1)} - M^{(1)}\frac{P_{e.trip}}{M_C^{(1)}} \tag{17}$$

$$\eta = -\int_{\delta_{trip}^{(1)}}^{\delta_u^{(2)}} P_a^{(2)} d\delta^{(2)} - \tfrac{1}{2}M^{(1)}\omega_{trip}^{(1)}{}^2 \tag{18}$$

3. SIME Configuration with Generator Tripping

3.1 Effects of generator tripping on transient stability

When transient instability occurs as a result of a serious system contingency, there are solutions; these solutions entail decreasing the acceleration area or increasing the deceleration area. Decreasing the fault removal time is the most common method used to decrease the acceleration area. When the acceleration area decreases and the fault is naturally removed, the phase angle of the generator is determined as a small value, and an increase of the deceleration area can be expected. However, the fault removal time is determined by the physical time of the protective relay device, and is used as a measure to evaluate the transient stability level; it is not used as a means of transient stabilization. Another method to decrease the acceleration area involves the constrained generation of the critical generator. Constrained generation can achieve both goals of decreasing the acceleration area and increasing the deceleration area because it lowers the mechanical output value. Therefore, constrained generation is often used as a measure to achieve transient stability.

Generator tripping differs from the above-mentioned methods. Generator tripping is generally performed after removal of the contingency and does not affect the acceleration area of the generator. However, when a generator is subsequently tripped, the effects of decreasing the mechanical output of the generator can be determined. In addition, the more substantial effect of blocking the cumulative acceleration energy can be achieved. If generator tripping is not performed, the acceleration area must be smaller than the deceleration area to prevent transient instability. This means that all the energy stored in generator inertia must be released as electrical energy. This can be simply summarized via the following inequalities:

$$A_{acc} < A_{dec} \tag{19}$$

Conversely, when generator tripping is performed, the energy stored as inertia of the tripped generator does not have to be released through the system. Hence, the total energy that must be released through the system after the generator is tripped is changed. This can be expressed via the following simple inequalities:

$$\left(A_{acc} - A_{trip}\right) < A_{dec} \tag{20}$$

3.2 Reflecting Generator Tripping on SIME

The reduction of the clearing time, or the constrained generation of the generator, does not yield much influence on the SIME configuration. Because these changes do not affect to the inertia parameter of SIME. Thus, the SIME can be calculated in the same manner as previously described. However, generator tripping introduces variability throughout the analysis, and the equation must be modified in consideration of the inertia of the tripped generator. A change of in inertia is reflected in all equations for SIME calculations, and thus has yields a fundamental effect on the SIME calculation results. Every element of the tripped generator, including the change of in inertia, must be excluded from the SIME calculations. If the set of generators to be tripped is *T*, the equation reflecting generator tripping is changed as follows:

$$\begin{cases} \delta_C \triangleq M_C^{-1} \sum_{i \in C\ i \notin T} M_i \delta_i \\ \delta_N \triangleq M_N'^{-1} \sum_{k \in N} M_k \delta_k \end{cases} \tag{21}$$

$$\left(M_C' = \sum_{i \in C\ i \notin T} M_i\ ,\ M_N = \sum_{k \in N} M_k\right) \tag{22}$$

$$\begin{cases} \omega_C = \dot{\delta}_C = M_C'^{-1} \sum_{i \in C\ i \notin T} M_i \omega_i \\ \omega_N = \dot{\delta}_\mathrm{N} = M_N^{-1} \sum_{k \in N} M_i \omega_k \end{cases} \tag{23}$$

$$\begin{cases} \ddot{\delta}_C = M_C'^{-1} \sum_{i \in C\ i \notin T} M_i \ddot{\delta}_i \\ \ddot{\delta}_N = M_N^{-1} \sum_{k \in N} M_i \ddot{\delta}_i \end{cases} \tag{24}$$

$$P_m = M'\left(M_C'^{-1} \sum_{i \in C\ i \notin T} P_{mi} - M_N^{-1} \sum_{k \in N} P_{mk}\right) \tag{25}$$

$$P_e = M'\left(M_C'^{-1} \sum_{i \in C\ i \notin T} P_{ei} - M_N^{-1} \sum_{k \in N} P_{ek}\right) \tag{26}$$

$$\left(M' = M_C' M_N / (M_C' + M_N)\right) \tag{27}$$

What is important here is the time at which the SIME is constructed. The SIME equation for generator tripping can be constructed via one of two methods. One method is to develop the SIME according to the conventional method before a generator trip and then express the generator trip in the post-trip SIME calculations. The second method is to calculate the SIME by accounting for the generator trip before it occurs. It seems reasonable to account for the tripped generator after it is tripped. However, in actual application, it is more effective to construct the SIME by considering the generator trip in advance. Although it seems that this will make it impossible to obtain an accurate calculation result for pre-generator trip analysis, considering a tripped generator in advance actually yields a

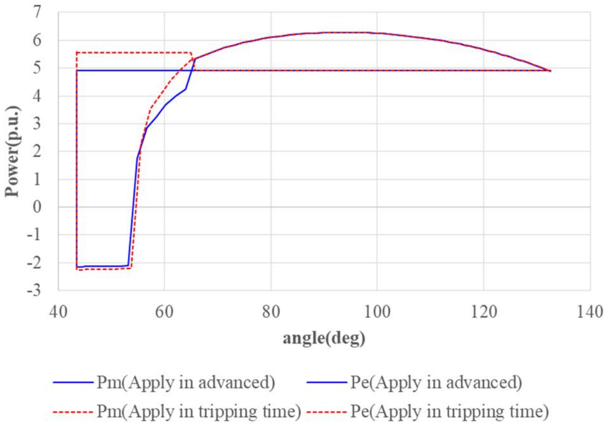

Fig. 2. Comparison of generator trip analysis in difference method

more accurate result when evaluating the effects of a generator trip.

Fig. 2 shows the construction of the SIME by adjusting the time at which the system accounts for a generator trip; it also shows a comparison of the results. The red dotted line indicates the power-angle curve of the OIMB applying the proposed SIME calculation method after a generator trip, whereas the blue solid line indicates the power-angle curve of the OMIB applying the generator trip in before occurrence. The middle section where the electrical output is quickly restored is the point in time at which the generator was tripped. The SIME equations for a post-tripped generator are identical; thus, the trajectories of the two analyses are identical.

However, by comparison the pre-tripped equations and the trajectories of the two curves are different. As can be seen in this figure, the curve showing where the equation is changed after the trip yields a significantly larger acceleration area than that of the method reflecting considering the trip in advance. To accurately interpret this, we must consider the effects of generator tripping on transient stability. When the generator is tripped, the acceleration energy accumulated via the inertia of the tripped generator is separated from the system. This means that the acceleration energy accumulated in the generator does not need to be released to the system via deceleration energy. In Fig. 2, the difference between the acceleration areas of the two pre-trip power-angle curves denotes the acceleration energy accumulated via the inertia of the tripped generator. In consideration of this principle, when evaluating the effects of a generator trip on transient stability, the generator must be tripped in advance and the results of SIME construction must be compared.

3.3 Evaluation of generator tripping effects

The effects of generator tripping can be quantitatively evaluated using the proposed method. The SIME composition is changed by as a result of generator tripping; however, this change includes consideration of the energy accumulated in the tripped generators. Therefore, even if the parameters comprising the SIME may be affected by a generator tripping, the analysis results can be directly compared. Thus, the effects of generator tripping can be analyzed by measuring the difference in the stability margin.

$$\eta_{effect} = \eta_{\text{gentrip}} - \eta_{basecase} \tag{27}$$

The optimal capacity of generator tripping for system stabilization can be determined as based on the generator trip effect that has been calculated as described above. Until the system is stabilized, generators are tripped in the descending order of the trip effect. If the generators have the same capacity, the effect can be simply applied, but if they have different capacities, they must be standardized by capacity. After achieving transient stability via generator tripping, the possibility of achieving stability by tripping generators of a smaller capacities should be examined.

4. Case study

4.1 Applying the proposed method in IEEE 39-Bus test system

To verify the proposed method, simulation was performed in IEEE 39-bus system [24]. Fig. 3 shows a schematic diagram of the IEEE 39-bus system. In this system, it can be observed that when a contingency occurs in the transmission line that interconnects bus No. 28 and bus No. 29, transient instability occurs in Generator 38. However, this system has only one bus No. 38 generator. When transient instability occurs in this system environment, the transient problem can be resolved by tripping Generator 38; however, this makes it difficult to evaluate the proposed

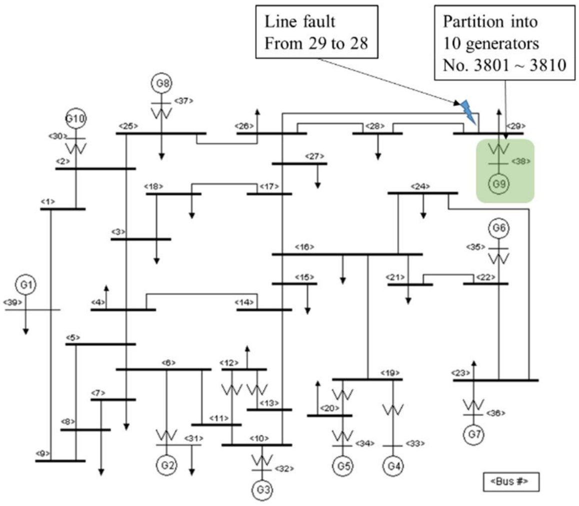

Fig. 3. Schematic for New England 39-bus and case study scenario [24]

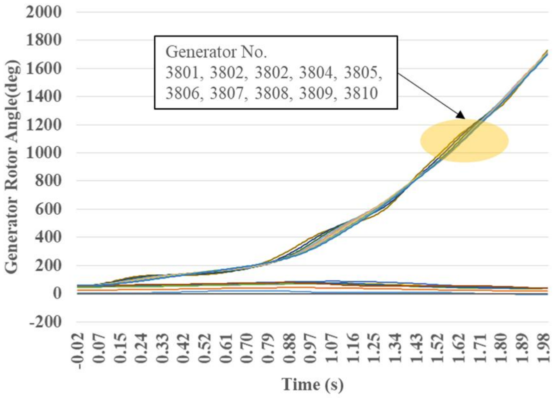

Fig 4. Transient stability analysis result when a generator tripping is not considered

method. Therefore, Generator 38 was partitioned into ten generators that were numbered as 3801–3810. If all parameters have the same values when the generator is divided, the generator trip effect appears as equivalent in each generator partition. Therefore, the inertial constant of the generator able to yield the largest effect on the SIME calculations was changed. Generator 3801 has the smallest inertia, whereas and Generator 3810 has is assigned the largest inertia. Fig. 4 shows the transient stability analysis of the tuned system. The 29-28 transmission line fault was applied and the fault duration was simulated as 0.1 s. As with the result observed, the ten partitioned generators became desynchronized.

Table 1. provides the transient stability margin results for the divided generators obtained via the proposed method. All stability margins become negative values because the system is not stabilized with the generator trip of a single machine. A smaller stability margin corresponds to less improvement in transient stability. The analysis results suggest that Generator 3801 has the most significant influence on transient stability, whereas Generator 3810 yields the weakest influence. Additionally, the acceleration and deceleration areas can be observed. The acceleration area was most reduced when Generator 3801 was tripped, whereas it was largest when Generator 3810 was tripped. In contrast, the deceleration area was largest when Generator 3801 was tripped and smallest when Generator 3810 was tripped.

Table 2 represents the evaluation results for implementation of the minimum generator trip calculation method. When the proposed method is used(case 1), transient stability can be achieved by tripping two generators. In contrast, if the generators are tripped in the ascending order of trip effect(case 2), three generators must be tripped. Because the partitioned generators have the same output, tripping three generators inhibits an increased amount of generator output. This finding confirms that the proposed method can minimize the number of generators that must be tripped to achieve transient stability.

Table 1. Transient stability margin calculation results for tripped generators 3801–3810

Tripped Generator	P_m (MW)	A_{acc} (p.u.)	A_{dec} (p.u.)	η (p.u.)
-	-	1.8035	0.7752	−1.0283
3801	83	1.5886	1.1695	−0.4191
3802	83	1.5864	1.1345	−0.4519
3803	83	1.5909	1.1120	−0.4789
3804	83	1.5995	1.0955	−0.5040
3805	83	1.6111	1.0814	−0.5297
3806	83	1.6252	1.0695	−0.5557
3807	83	1.6401	1.0601	−0.5800
3808	83	1.6571	1.0537	−0.6034
3809	83	1.6755	1.0505	−0.6251
3810	83	1.6949	1.0504	−0.6445

Table 2. Comparison of simulated generator trip capacity

Case	Tripped generator	Tripped capacity (MW)
Case 1	3801, 3802	166
Case 2	3810, 3809, 3808	249

Fig. 5 illustrates the acceleration power, Pa, curve of generator 3801 and 3810. Analysis results show a comparison of Generator 3801 and Generator 3810 demonstrates that the former yields the most desirable results and the latter yields the most unfavorable result. The blue solid line in this figure indicates the SIME analysis results for Generator 3801, and the red solid line indicates the SIME analysis results for Generator 3810. The differences between the respective acceleration and deceleration areas of the generators can also be seen in this figure.

4.2 Comparison with conventional method

This section compares the results obtained via the conventional method to those obtained via the proposed method. The system configuration and scenario are the identical to those of the previously described simulation. Table 3 shows the results of conventional methodology for each tripped generator. Results show that the tripping effect

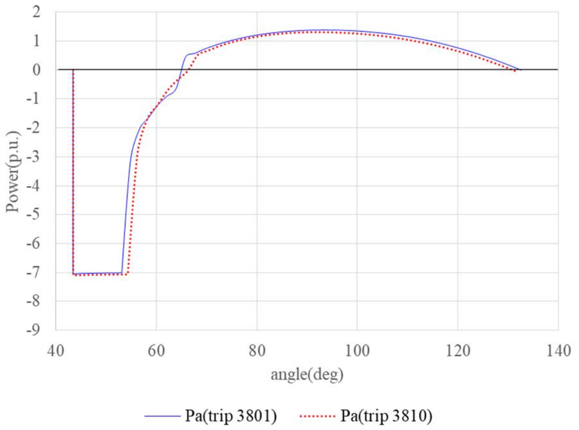

Fig. 5. Comparison of SIME results for tripped generators 3801 and 3810

Table 3. Transient stability margin calculation results for tripped generators 3801–3810

Tripped Generator	P_m (MW)	A_{acc} (p.u.)	A_{dec} (p.u.)	η (p.u.)
-	-	1.8035	0.7752	-1.0283
3801	83	1.5886	1.7693	0.1807
3802	83	1.5864	1.7509	0.1645
3803	83	1.5909	1.7327	0.1418
3804	83	1.5995	1.7166	0.1171
3805	83	1.6111	1.7030	0.0919
3806	83	1.6252	1.6925	0.0673
3807	83	1.6401	1.6848	0.0447
3808	83	1.6571	1.6795	0.0224
3809	83	1.6755	1.6764	0.0009
3810	83	1.6949	1.6752	-0.0197

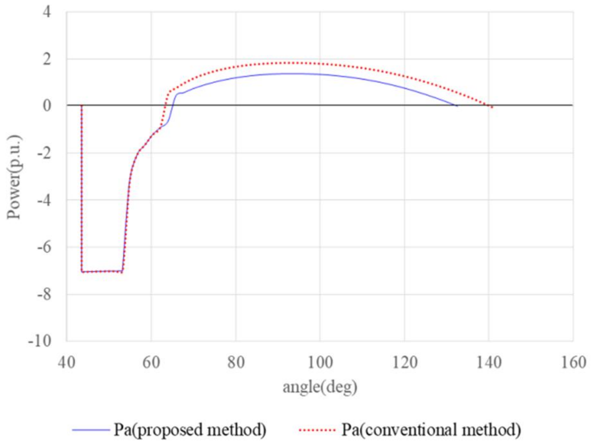

Fig. 6. Comparison of proposed and conventional method for generator 3801

of Generator 3801 is the most influential, whereas the tripping effect of Generator 3810 is the least influential. These results are identical to those of obtained via the proposed method. However, according to the conventional method, one generator tripping is sufficient to prevent transient instability. From the results obtained via the proposed method, it has been confirmed that at least two generators should be tripped. This difference is due to the fact that the conventional method examines the generator tripping effects that have been derived as based on various estimates and assumptions.

Fig. 6 compares the acceleration power, P_a, curves for the conventional method and proposed method results when the Generator 3801 is tripped. The acceleration areas resulting from the conventional method and the proposed method are not significantly different. However, after the generator trip, the conventional method results in a wider deceleration area than the proposed method. This is because the conventional method does not reflect the change in the electrical output due to the generator trip. Therefore, the proposed method should be used to accurately examine the effects of a generator trip on transient stability.

4.3 Applying the proposed method in 2017 KEPCO system

The proposed method is applied to the Korean power system in 2017. Contingency is a 765kV double fault, where the critical generator group is the Dangjin power plant. The Dangjin Power Plant located in the west coast area. The parameters and models of the generators are slightly different, and the method of generator connection is somewhat different. The biggest difference is that the 26201 and 26202 generators are connected via a 154kV network. 26209 and 26210 generators have a capacity about double that of other generators.

Table 4 examines the transient stability effect of each generator. Since the capacity of each generator is different, examination of the influence is evaluated as a change of unstable margin due to 1p.u. Table 5 shows the effective order of the generators through such a change in stability margin. It also indicates the generators to be shut down for transient stabilization when applying the most effective and least effective methods. When tripping in the order of effect, it is possible to reduce one generator tripping to prevent transient instability, rather than blocking in order of decreasing effectiveness. Fig. 6. shows the maximum angle difference of the generator when the same capacity of 3100MW is tripped. When tripping in an ineffective

Table 4. Transient stability margin calculation results for Dangjin generators

Tripped Generator	P_m (MW)	A_{acc} (p.u.)	A_{dec} (p.u.)	η (p.u.)
-	-	12.8595	-0.5639	-12.2955
26201	520	12.4740	-0.7165	-11.7574
26202	520	12.4494	-0.7409	-11.7084
26203	520	12.3587	-0.7938	-11.5650
26204	520	12.3585	-0.7940	-11.5645
26205	520	12.3419	-0.8115	-11.5304
26206	520	12.3365	-0.8333	-11.5032
26207	520	12.3457	-0.8246	-11.5211
26208	520	12.3487	-0.8012	-11.5475
26209	1020	12.3525	-0.8106	-11.5419
26210	1020	12.3520	-0.8001	-11.5520

Table 5. Comparison of simulated generator trip capacity for Dangjin generators

Tripped Generator	$\Delta\eta$ (p.u.)	Order of effect	Effective tripping order	Ineffective tripping order
26201	0.5381	10		O
26202	0.5871	9		O
26203	0.7306	8		O
26204	0.7310	7		O
26205	0.7651	3	O	
26206	0.7924	1	O	
26207	0.7745	2	O	
26208	0.7480	5	O	O
26209	0.7537	4	O	
26210	0.7436	6		O
Total Tripped MW			3100MW	3620MW

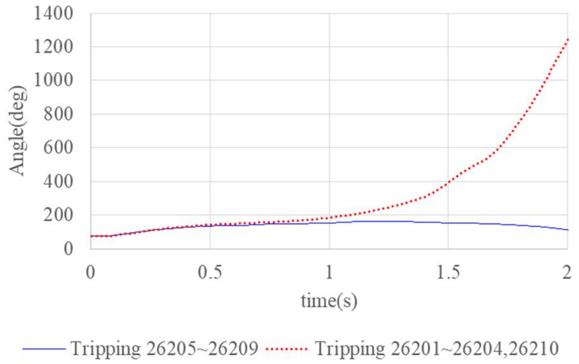

Fig. 7. Maximum angular gap comparison with different tripping generator group configurations

sequence, additional generator tripping is required for transient stabilization.

5. Conclusion

In studies employing the conventional method, power generation rescheduling is mainly used as a method to secure transient stability. However, generator tripping can also be a good measure to ensure transient stability. Generator tripping offers the advantage of no rescheduling cost. The effects of generator tripping cannot be accurately calculated via conventional SIME methods. Thus, the results of this study can be used as a method to assess the effectiveness of generator tripping.

This study proposed a SIME calculation method that accurately describes the effects of generator tripping on transient stability. The proposed method was evaluated for an IEEE 39-bus system and KEPCO system. In IEEE 39-bus system, each generator was configured to have different trip effects even though they have the same capacity with different inertial constants. The simulation results showed that the generators yielded different trip effects. When the generators were tripped in the descending order of trip influence, transient stability could be achieved with a lesser trip capacity than that required when the generators were tripped in the ascending order of trip influence. In KEPCO system, the Dangjin plant is examined by the proposed method. Simulation result of KEPCO system also shows a similar trend with result of IEEE 39-bus system.

The proposed method can be implemented in various research fields currently employing the conventional SIME method. Regarding on-line monitoring, it is possible to determine whether the trip capacity is sufficient to achieve transient stability when the generator is tripped via the Special Protection Scheme (SPS). It is expected that the proposed method can be used to implement generator tripping as a control measure for TSCOPF.

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