Assessment of Transient Stability using Rate of Change of the ISE in Transmission System

Gi-Hyeon Gwon, Ji-Kyung Park, Yun-Sik Oh, Sung-Bum Kang, Hun-Chul Seo, Chul-Hwan Kim, Toshihisa Funabashi

***Abstract*-- The operation of reclosing can jeopardize the stability and damage the equipment of power system under the unstable conditions due to a fault in transmission system. The transient stability must be evaluated to determine whether the transmission system is stable or unstable prior to reclosing. This paper proposes a method to assess the transient stability using rate of change of Integral Square Error (ISE). The assessment method is developed by using Dynamic Link Library (DLL), which is one of functions in ElectroMagnetic Transient Program-Restructured Version (EMTP-RV). The developed DLL can assess the stability of the system, and also control operation of reclosing. This method can prevent the conventional protection scheme from reclosing under unstable status of transmission system. In this paper, the analysis of stability for the transmission system is performed by using EMTP-RV. This paper shows the simulation results using proposed ISE method in 154kV Korea transmission system.**

***Keywords*: reclosing, ISE, DLL, EMTP-RV, transmission system, transient stability.**

I. Introduction

Reclosing is one of the useful protection methods to improve the continuity of power supply and economics, and reliability of system. This reclosing is very effective scheme, because most of faults are transient in transmission system. Especially, high-speed reclosing facilitates fast restoration of power system and maintains stability. However, if system separation happens with high angle, conventional reclosing may result in aggravation of stability. Therefore, the reclosing scheme is needed the assessment of stability to block the reclosing in instability prior to closing of breakers [1-3].

This paper proposes a method of stability assessment using the rate of change of the Integral Square Error (ISE), which is an index of performance for system operation [4-6]. In this paper, the value of ISE is summation of the squared differences between the deviation of voltage phase angle and the initial angle before a faulted line is re-energized. The rate of change of ISE is shown in curve slope of the ISE.

The proposed method is developed by using Dynamic Link Library (DLL). The DLL enables users to build advanced program for interaction with ElectroMagnetic Transient Program-Restructured Version (EMTP-RV) using programming language such as C++, Java, and Fortran [7-8]. The developed DLL can determine the stability of the system, and also provide reasonable evidence to whether to operate reclosing.

In this paper, the analysis of stability for the transmission system is performed by using EMTP-RV according to the change of initial voltage phase angles. This paper shows the simulation results and analyses of the stability assessment using proposed ISE method in 154kV Korea transmission system.

II. Rate of Change of ISE

The ISE is one of the time domain solutions, which can evaluate a performance of system. This method can be applicable to assess the stability of power system [4]. The difference of voltage phase angles between both ends of the transmission line is increased due to trip of circuit breaker in the faulted transmission system. In this case, transient stability can be evaluated by using ISE through the change of the voltage phase angle difference. This method is influenced by interval of time when swing of rotor angle is converged to a certain value, and amplitude of swing. The ISE can be expressed by following [5-6].

$$ISE = \int_0^\infty [\delta(t) - \delta_0]^2 \, dt \tag{1}$$

Where

$\delta(t)$: Voltage phase angle

δ_0 : Initial angle

Fig. 1(a) shows curve of voltage phase angle and initial angle. The power system is operated with initial phase angle. But, if a fault occurs suddenly in transmission line, the voltage phase angle is increased. Then, circuit breakers on the transmission line is tripped to clear a fault, thus voltage phase angle is swung as shown in Fig. 1(a). The ISE is a value that is summation of the squared differences between the deviation of voltage phase angle and the initial angle before a faulted line is re-energized. When swing of angle is decreased after

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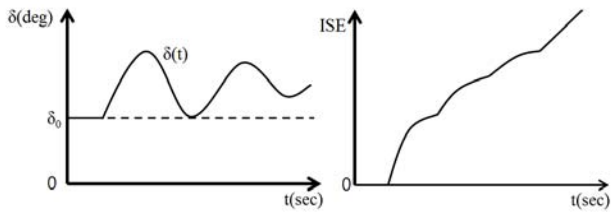
fault clearing, the ISE is increased rapidly and then finally has a constant slope, as shown in Fig. 1(b). The rate of change of ISE (i.e., slope of the ISE) declined to a small value, because voltage phase angle difference does not swing any more. Thus, in this case, the power system is stable. However, when a power system is unstable, the ISE and the rate of change are increased progressively. Therefore, stability of power system can be assessed by amplitude of this rate. The rate of change of the ISE is calculated from following.

$$\Delta ISE = \frac{ISE(t+\Delta t) - ISE(t)}{\Delta t} \tag{2}$$

Where

ΔISE : The rate of change of the ISE



(a) Curve of voltage phase angle and initial angle (b) Curve of ISE

Fig. 1. Curve of voltage phase angle after opening of circuit breakers.

III. Dynamic Link Library

The Dynamic Link Library is available in EMTP-RV environment to allow users to develop models. During the EMTP-RV is operated, the program is connected with DLL file, which is composed by user. The EMTP-RV environment supplies various code sources for DLL. EMTP-RV adopts the standard of plug-in means to operate interaction with DLL. Also, users can produce an algorithm or elements of system what they want. To build DLL, some programming languages are need such as FORTRAN and C++. Fig. 2 shows interaction between EMTP-RV and DLL. EMTP-RV Core Code requests participation of DLL file to find the solution for the power system. Then, the DLL is going to participate in Core Code as necessary [7-8].

In this paper, a DLL function is used to compute the rate of change of ISE and to control the operation of recloser. The DLL file is generated by using Intel Visual FORTRAN Composer.

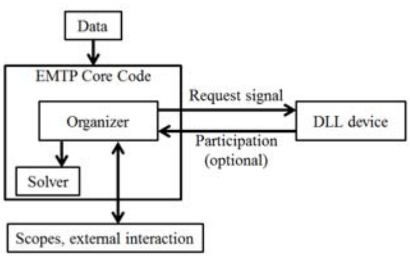


Fig. 2. Interaction between EMTP-RV and DLL.

As shown in Fig. 3, the voltage phase angle is collected from each scope on EMTP-RV. At next stage, the ISE is calculated in real time after the reclosing is operated at leader end, and then, the rate of change of ISE is computed by using (2). If this rate satisfies a defined condition, DLL function allows the reclosing to initiate at the follower end of transmission line. If the rate is large, the ISE is calculated during delayed time continuously and previous procedures are repeated. Nevertheless, if the rate is larger than the condition again, reclosing is blocked to prevent out of synchronism. Fig. 4 shows the transmission system model, connected with DLL device to computation of the ISE and to control circuit breakers.

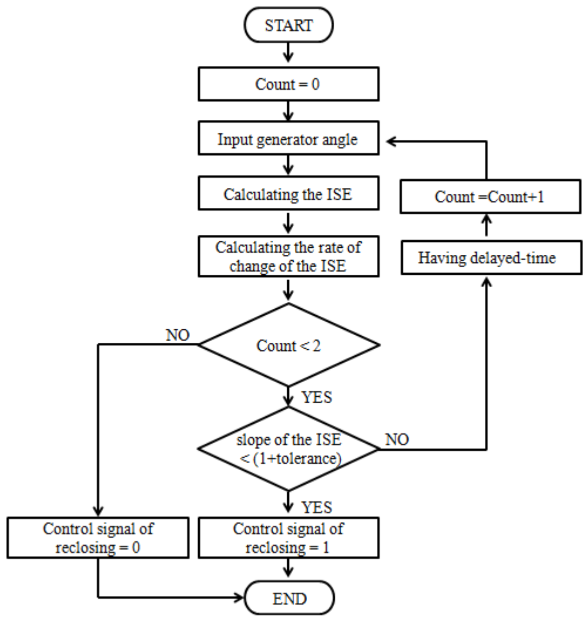


Fig. 3. Flow chart of developed DLL function.

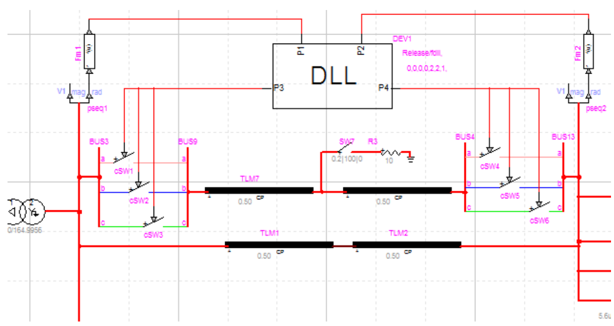


Fig. 4. Connection between DLL and transmission system in EMTP-RV.

IV. Simulation and Results

A. System Model

This paper models a 154kV Korea transmission system using EMTP-RV. The modeled system, as shown in Fig. 5, is comprised of generators and transformers, infinite bus, and transmission lines, which is modeled with distributed parameters and with double lines. The distance between S. C.

T/P and D. C. bus is about 34.4(km). This transmission system adopts high speed reclosing scheme and synchronism check supervising reclosing between two portions of a system.

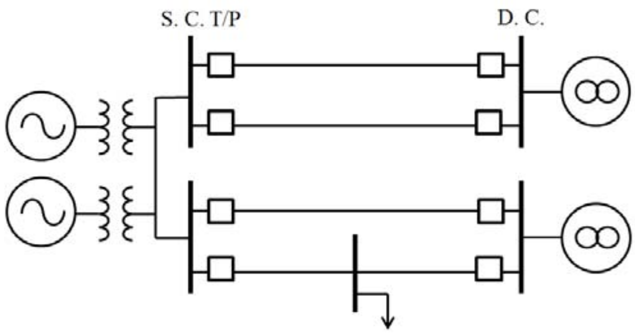


Fig. 5. The equivalent model of 154kV transmission system.

B. Simulation Conditions

In this paper, several conditions of simulation are assumed to verify the proposed assessment method of stability using the rate of change of the ISE, as shown in Table I. A three-phase ground transient fault is happened in the middle of single line between S. C. T/P and D. C. bus. The both circuit breakers of ends is tripped due to the fault occurring. After fault clearing, the ISE is calculated before operating of leader end reclosing or follower end reclosing. Whether to permit the reclosing is determined by using the proposed rate of change. Fig. 6 shows reclosing sequence for 154kV Korea transmission system. This system has the delayed time of 1.8(sec) for synchronism check.

TABLE I
CONDITIONS OF THE SIMULATION

Parameters	Value
Fault occurring time	0.2(sec)
Fault clearing time	0.3(sec)
Tolerance in Fig. 3	1
Delayed-time in Fig. 3	1.8(sec)
Δt in (2)	0.1(sec)
Operating time of CB	0.05(sec)

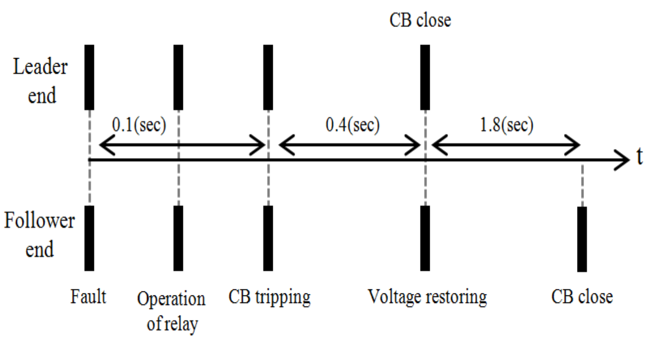


Fig. 6. The sequence of reclosing with synchronism check

C. Simulation Results

Fig. 7 show voltage phase angle between two buses under the stable condition. Thus, in this case, reclosing operation is proper to restore the system considering stability of the power system.

Fig. 8 shows the ISE curve for the case of Fig. 7. The value of ISE is quite small, and ΔISE is smaller than defined limitation before leader reclosing and follower reclosing. Thus, the follower reclosing is allowed and the system is restored successfully.

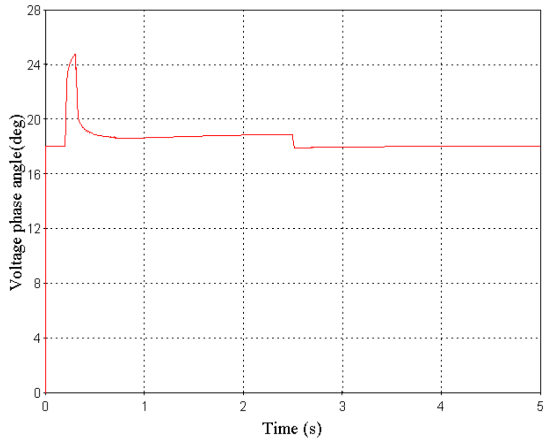


Fig. 7. The curve of voltage phase angle in stable system.

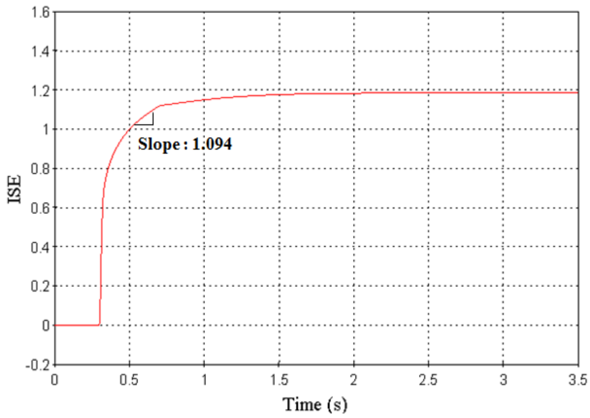


Fig. 8. The curve of ISE in stable system.

However, for a case of unstable transmission system due to high initial angle, as shown in Fig. 9, the reclosing operation leads to out-of-step between two buses. This unsuccessful reclosing can damage to equipment of the power system. Thus, in this case, blocking of reclosing must be considered.

Fig. 10 shows ISE curve for case of Fig. 9. Before follower reclosing, ΔISE is calculated by using DLL function and its value is very large as 961.339. The ΔISE is exceed the defined limitation, thus follower reclosing can be blocked to prevent unsuccessful reclosing. The protect system can recognize the stability of transmission system using ΔISE before reclosing operation in unstable condition, so that it can reduce the effect of unsuccessful reclosing on the power system.

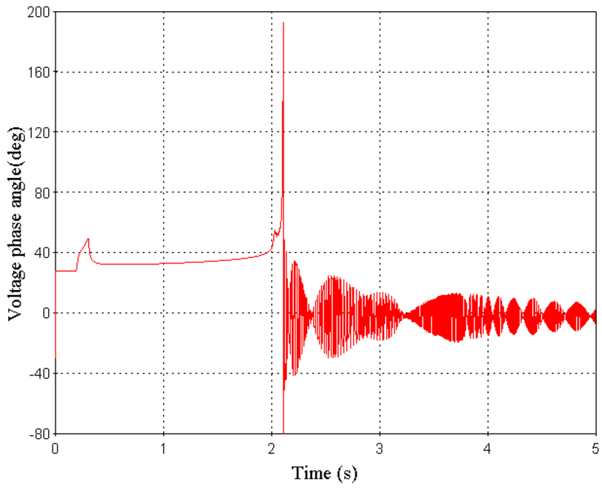


Fig. 9. The curve of voltage phase angle in unstable system.

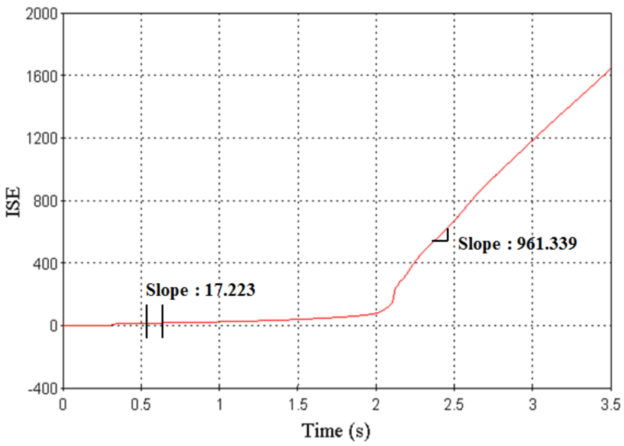


Fig. 10. The curve of ISE in unstable system.

Fig. 11 shows ΔISE before each reclosing with respect to initial angle of power system. The ΔISE value increases as the initial angle increases. For initial angles having 10˚ to 24˚, the transmission system is stable. While the system is unstable for cases of 26˚ and 28˚. For initial angles having 10° to 20°, the first ΔISE is smaller than the value of limit. In these cases, the system is stable, so that simultaneous operation of the reclosing at both ends is useful to reduce the dead time. For initial angles with 22° and 24°, the first ΔISE is larger than defined condition. After delayed time, the second ΔISE is recalculated and this value satisfies the condition. Thus, simultaneous reclosing at both ends is impossible and sufficient dead time is needed to calculate ΔISE again after leading reclosing. Lastly, for initial angles of 26° and 28°, two ΔISE is larger than the limitation, as shown Fig. 10. Thus, in these cases, the transmission system is unstable and the follower reclosing is blocked, and then closed leader circuit breaker should be opened again.

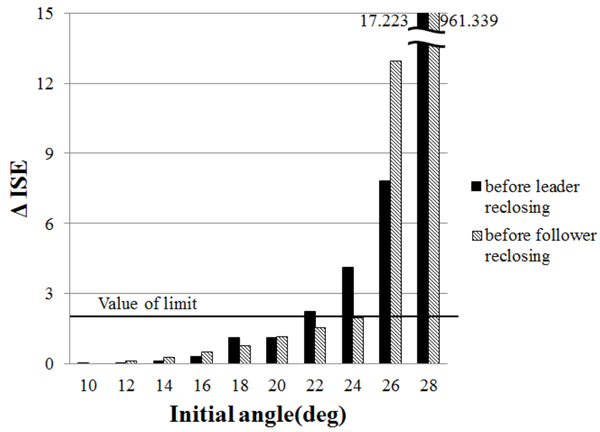


Fig. 11. The value of ΔISE with respect to initial angle of power system.

V. Conclusions

This paper has presented a proposed method of stability assessment, which is rate of change of the ISE, and has verified this method through application for 154(kV) Korea transmission system using EMTP-RV. This method can evaluate that whether the power system is stable or not before operation of reclosing. In this paper, DLL function is developed to compute the rate of change of the ISE in real time.

It can be concluded from the results of simulation that the proposed method can allow simultaneous reclosing at both ends for stable case to restore the transmission system quickly and block the reclosing operation for unstable case to prevent damage for transmission system.

VI. References

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