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An Adaptive Autoreclosure Scheme with Reference to Transient Stability for Transmission Lines

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Abstract – Autoreclosure provides a means of improving power transmitting ability and system stability. Conventional reclosure adopts the fixed dead time interval strategy, where the reclosure is activated after a time delay to restore the system to normal as quickly as possible without regard to the system conditions. However, these simple techniques cannot provide optimal operating performance. This paper presents an adaptive autoreclosure algorithm including variable dead time, optimal reclosure, phase-by-phase reclosure and emergency extended equal-area criterion (EEEAC) algorithm in order to improve system stability. The reclosure algorithm performs the operations that are attuned to the power system conditions. The proposed adaptive reclosure algorithm is verified and tested using ATP/EMTP MODELS, and the simulation results show that the system oscillations are reduced and the transient stability is enhanced by employing the proposed adaptive reclosure algorithm.

Keywords: Autoreclosure, Adaptive reclosure, Optimal reclosing time, Phase-by-phase reclosure, Transient stability EMTP

Nomenclature

V_f	Transient energy after fault
V_k	Kinetic energy after fault
V_p	Potential energy after fault
M	Inertia constant of the generator
ω	Angular velocity of the generator
P_m	Mechanical power input of the generator
P_e	Electrical power output of the generator after fault
δ	Generator angle after fault
δ_s	Stable equilibrium point after fault
δ_{RC}	Generator angle at the moment of the pre-reclosing
V_{RC}	Transient energy after reclose
P_{eRC}	Electrical power output after reclose
δ_{sRC}	Stable equilibrium point after reclose
P_M	Mechanical power
P_E	Electrical power
P_A	Accelerating power
P, B, C	Parameters calculated using the least square method or the curve fitting method
A_{ACC}	Acceleration area
B_{DEC}	Deceleration area
T_V	Time calculated by variable dead time algorithm
T_O	Time calculated by optimal reclosing algorithm

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1. Introduction

Reclosures are a means of increasing the dependability of a supply. Stability must consider permanent faults and line outages as a worst-case scenario. However, unsuccessful reclosure in response to a permanent fault may threaten system stability and aggravate severe damage to the system and equipment. For this reason, it is very important in a reclosure sequence to distinguish a permanent fault from a transient fault. However, conventional autoreclosure techniques adopt fixed dead time interval techniques, where the breaker recloses as quickly as possible after a prescribed period following tripping operation regardless of whether the fault is permanent or transient. The various methods for distinguishing between a permanent fault and a transient fault have been proposed [1-3]. Especially, real time transient stability using EEEAC and various fault conditions are considered in [3]. Although a permanent fault can be distinguished from a transient fault and the secondary arc extinction time can be estimated using these proposed methods, the faster dead time proposed is not necessarily better for enhancing the transient stability because reclosing immediately following secondary arc extinction (in the case of a transient fault) can lower the chance of a successful reclosure. Importantly, the reclosing transients can be accentuated and have a detrimental effect on the system [4]. Research has shown that the optimal reclosing time is the instant when the transient energy of the post-reclosing system is minimum, because larger transient energy corresponds weaker system stability, causing the system to oscillate heavily [5-6]. Optimal reclosure can also improve the transient stability [7-8]. These methods are based on a technique that reduces the impact on the system during the reclosing procedure.

This paper firstly describes three different autoreclosure schemes. The first autoreclosure scheme is based on a variable dead time control algorithm which is able to ascertain the secondary arc extinction time and distinguish a permanent fault from a transient fault using the voltage waveform of the tripped line. The second is a scheme based on optimal reclosure by using the generator angle in real-time in relation to the Transient Energy Function (TEF). The third is a scheme based on modified phase-by-phase reclosure whereby the optimal reclosing time is used as the time delay. In addition, an adaptive autoreclosure algorithm is suggested as a combination of the phase-by-phase reclosure, Emergency Extended Equal-Area Criterion (EEEAC), the variable dead time reclosure, and optimal reclosure. Finally, simulation results are presented and discussed. The simulation is implemented using ATP/EMTP MODELS, and the simulation results show the effectiveness of the suggested schemes.

2. Fault Types and Autoreclosure

It is very important in a reclosure sequence to distinguish clearly between a permanent fault and a transient fault. In this respect, conventional autoreclosing techniques adopt a fixed dead time interval policy irrespective of whether a fault is transient or permanent in nature and hence cannot guarantee that reclosing will be successful, even though statistics show a very high percentage of faults are temporary [9].

In this paper, the voltage waveforms are used to distinguish the fault types and estimate the secondary arc extinction time in the three-phase autoreclosure as well as the single-pole autoreclosure [1, 9]. The detailed description is discussed in Ref. [1]. Fig. 1 shows the typical voltage waveform at fault conditions. In Fig. 1, fault occurs at point A and circuit breakers open at point B. In case of transients fault, the recovery voltage is occurred at the extinction instant of secondary arc which is at point C, however, the permanent fault is not. Using these characteristics, the estimation of transients fault and the secondary arc extinction time is possible.

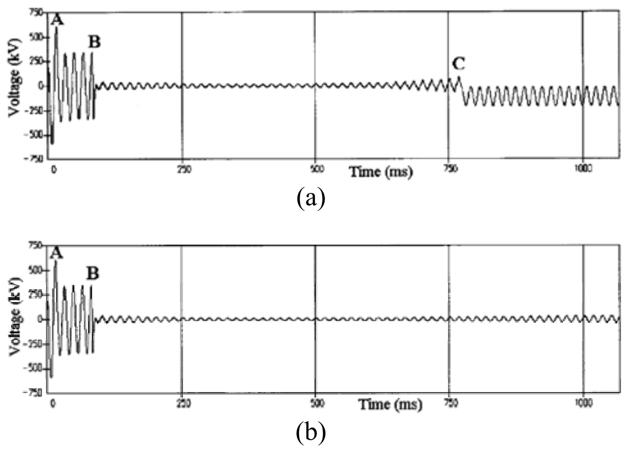

Fig. 1. Typical voltage waveform: (a) transient fault; (b) permanent fault

3. Optimal Reclosing Time

Generally, it is believed that the faster the line reclosing is, the better the system stability will be for a transient fault. However, the faster line reclosing may not be better for the transient stability in some cases due to transient energy at the moment of reclosing CB. It is well known that system stability changes in proportion with transient energy and a higher transient energy weakens system stability and increases oscillation.

In a one machine infinite bus (OMIB), the transient energy function after a fault is given as [5, 9, 10]:

$$V_f = V_k + V_p = \frac{1}{2} M\omega^2 - P_m(\delta - \delta_s) - P_e(\cos\delta - \cos\delta_s) \quad (1)$$

The total transient energy, which is the sum of the kinetic and potential energy, remains constant after a fault, and the energy is exchanged between the kinetic and potential energy[11].

At the instant of pre-reclosing, the kinetic energy is:

$$V_k = V_f + P_m(\delta_{RC} - \delta_s) + P_e(\cos\delta_{RC} - \cos\delta_s) \quad (2)$$

At the instant of post-reclosing, the transient energy after the post-reclosing is written as:

$$V_{RC} = V_k - P_m(\delta_{RC} - \delta_{sRC}) - P_{eRC}(\cos\delta_{RC} - \cos\delta_{sRC}) \quad (3)$$

Substituting (2) into (3) results in:

$$\begin{aligned} V_{RC} = V_f - P_m(\delta_s - \delta_{sRC}) - P_e\cos\delta_s + P_{eRC}\cos\delta_{sRC} \\ -(P_{eRC} - P_e)\cos\delta_{RC} \end{aligned} \quad (4)$$

When the transient energy V_{RC} in (4) reaches its minimum, it is the optimal reclosing instant. At the instant of reclosing, the variables except for δ_{RC} are the fixed values, and V_{RC} is determined by the generator angle δ_{RC} at the instant of reclosing. In a transient fault, the electrical power output of post-reclosing P_{eRC} is usually larger than the electrical power output of pre-reclosing P_e. Therefore, V_{RC} becomes its minimum value when the absolute value of δ_{RC} is a minimum [10].

The algorithm to find the optimal reclosing time based on point of transient energy is shown in Fig. 2. The angular velocity is calculated in block ①; here the angular velocity ω[n] is calculated by low-pass filtering of the difference-value between δ[n] and δ[n-1], and then the optimal reclosing time is deduced in block ② when the rate of

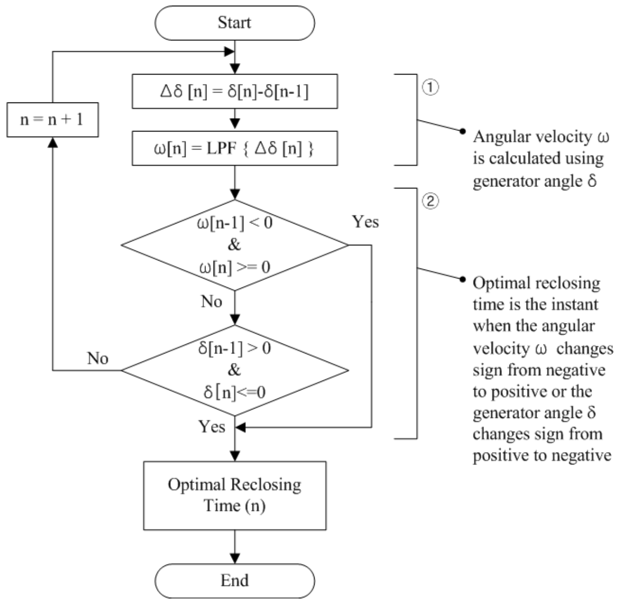

Fig. 2. Flowchart to find the optimal reclosing time

change of velocity changes from negative to positive or when the rate of change in angle changes from positive to negative, i.e. the absolute value of the generator angle becomes minimum. The 4th block of Fig. 2 is the block to satisfy above first case and the 5th block of Fig. 2 is the block to satisfy above second case. This method can be extended to a multimachine system using emergency EEAC whereby a multimachine system is replaced by the OMIB system, and the generator angle of the equivalent OMIB may be used to find the optimal reclosing time in Fig. 2.

4. Phase-by-Phase Reclosure

A phase-by-phase reclosure whereby the phases are reclosed sequentially has been proposed in order to reduce the torsional torques induced in turbine-generator shafts and improve the transient stability during high-speed reclosure, i.e. during three-phase reclosing. The first phase is reclosed at t1, the second phase at (t_1+Δt) and the third phase at (t_1+2Δt), where Δt is an adjustable time delay [7]. Reference [7] shows the effectiveness of the phase-by-phase reclosure on the turbine-generator shaft torsional torques and the relationship between the maximum torsional torques and the reclosing time. In the case of phase-by-phase reclosure, reclosing one phase will allow some of the turbine-generator electric power to be transferred to the infinite bus system. On the other hand, the power transfer to the infinite bus system from the turbine-generator will be reduced to zero at time interval between the open of all the three phases of faulted circuit and the reclosing, and hence results in greater acceleration of the generator rotor than one in the case of the phase-by-phase reclosure. Therefore, it can be concluded that

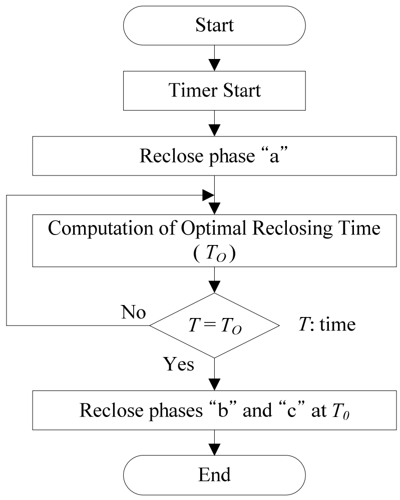

Fig. 3. Flowchart for the phase-by-phase reclosure using the optimal reclosing time as the time delay

sequential reclosure can also enhance the transient stability of the system [7]. Herein, the time delay Δt is the fixed value. However, in this paper, the optimal reclosing time is used for the time delay to improve transient stability, and Fig. 3 shows the flowchart for the reclosing. Phase "a" is reclosed after a time delay and the phases "b" and "c" are reclosed at the optimal reclosing time as described in section III.

Here, the first reclosing is used in order to transform the first-swing instability into the first-swing stability, and the effectiveness is shown in the simulation results. This phase-by-phase reclosure may disperse the impact that is added to the system by the simultaneous reclosure. The phase by phase reclosure is helpful for some slightly unstable events. It can be applied to the strongly connected system. Also, in case of Extra High Voltage (EHV) transmission system, as the nominal voltage becomes higher, the space between two phases also becomes wider and then the possibility of single line-to-ground fault becomes higher. Therefore, the possibility of application of single pole reclosing is high. In this respect, the phase by phase reclosure is very efficient. It also has advantages that the damage of turbine-generator shaft can be reduced and the power can be continuously transferred to the transmission system through the first reclosed phase.

5. Adaptive Reclosure

5.1 First swing stability and optimal reclosing time

The optimal reclosing instant is the time when the transient energy of the post-reclosing system is minimum. In the case that the first swing is stable, the transient energy of the post-reclosing system oscillates and the position where its direction is changed from negative to positive exists. On the other hand, in the case that the first swing is

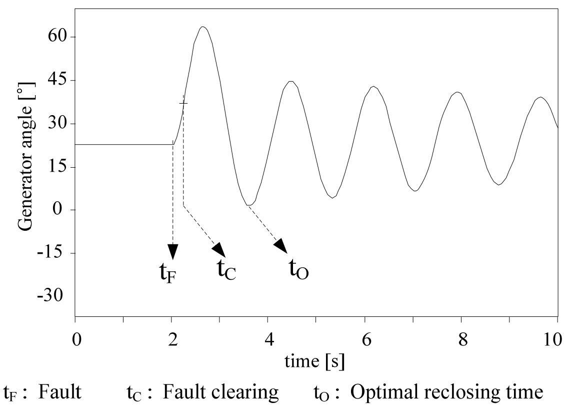

Fig. 4. Generator angle in the case of first swing being stable

unstable, the transient energy increases monotonically (with no oscillation) until the generator angle reaches beyond 180° and the position where its direction is changed does not exist, and the faster the line reclosing is, the smaller the transient energy of the post-reclosing is. However, the simulation shows that the stability cannot be maintained by simply using the fast simultaneous reclosure. In an OMIB, as seen in (4), the transient energy is proportional to the negative of the cosine value of the generator angle at the instant of reclosing. In case of transient faults, Fig. 4 shows the generator angles and the optimal reclosing time when the first swing is stable.

5.2 Real-time transient stability assessment using emergency EEAC

The principle of emergency EEAC is that the generator models are decomposed into two subsets of the critical machines and the remaining machines. These subsets are equivalent to two machines and to OMIB [9]. In the OMIB, Equal-Area Criterion (EAC) is utilized to assess stability. For a certain fault, the critical machines are identified by using the gap between the rotor angles. However, this method cannot be used for real-time Transient Stability Assessment (TSA) because the angle gap cannot be separated during the short period. Reference [11] presents two criteria to identify the critical machines using the rotor speed and the schemes of emergency EEAC to assess transient stability in real-time.

In the case of fault at the transmission lines that may not be close to the generating station, the rotor speed of the generator does not fluctuate significantly. Therefore, criterion 2 in ref [11] can be applied to these cases. Hence, the OMIB can be obtained and the proposed algorithm in this paper can be applied. In addition, the fault at the remote transmission lines from the generating station does not affect the transient stability significantly. Therefore, this paper applies the proposed reclosing schemes to the transmission lines that may be close to a generating station as worst cases.

In the equivalent OMIB system, the P_A-δ curve is given as [11-12] :

$$M\frac{d^2\delta}{dt^2} = P_M - P_E = P_A = P + B\cos\delta + C\sin\delta \qquad (5)$$

P_A can be calculated when δ is measured and M is known previously. The parameters P, B and C can also be calculated using the least square method or the curve fitting method, and the accelerating and decelerating areas can be calculated for transient stability assessment. The parameters P, B and C using the least square method are given as [11]:

$$\begin{bmatrix} P \\ B \\ C \end{bmatrix} = (A^T A)^{-1} A^T b \qquad (6)$$

$$\text{where, } A = \begin{bmatrix} 1 & \cos\delta(\Delta t) & \sin\delta(\Delta t) \\ 1 & \cos\delta(2\Delta t) & \sin\delta(2\Delta t) \\ \vdots & \vdots & \vdots \\ 1 & \cos\delta(n\Delta t) & \sin\delta(n\Delta t) \end{bmatrix}, \quad b = M\begin{bmatrix} \ddot{\delta}(\Delta t) \\ \ddot{\delta}(2\Delta t) \\ \vdots \\ \ddot{\delta}(n\Delta t) \end{bmatrix}$$

In Fig. 5, δ is recorded from δ_O to δ_A. At δ_A, the areas A_1 and B_1 are calculated using the recorded data δ, and the area B_2 is calculated using the predicted P_A-δ curve of the dashed curve. Here, if the acceleration area A_1 is larger than the deceleration area (B_1+B_2), then the system will lose stability. Herein, the transient stability margin can be given as [11]:

$$\eta_1 = \frac{B_{DEC} - A_{ACC}}{A_{ACC}} \quad \text{or} \quad \eta_2 = B_{DEC} - A_{ACC} \qquad (7)$$

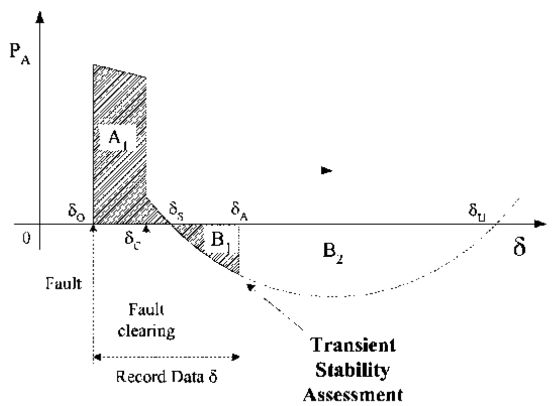

Fig. 5. P_A-δ curve using emergency EEAC for transient stability assessment

5.3 Adaptive reclosure algorithm

The block diagram of the generator angle measurement

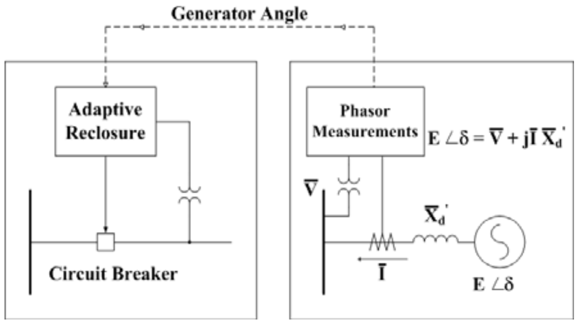

Fig. 6. Block diagram of the generator angle measurement for the proposed adaptive reclosure relay

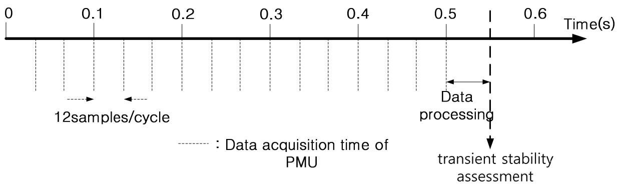

Fig. 7. Time sequence about PMU data acquisition and transient stability assessment

for the proposed adaptive reclosure relay is shown in Fig. 6, where the relay uses the voltage at the transmission line for the variable dead time control scheme and the generator angle for the optimal reclosing, phase-by-phase reclosing and transient stability assessment. Here, the generator angle is obtained from the phasor measurements at the generator terminal [13-14]. The proposed algorithm requires the Phasor Measurement Unit (PMU) as shown in Fig. 6.

Fig. 7 shows the time sequence about PMU data acquisition and transient stability assessment. PMU generally collects the data on 30times/sec and hence it collects data on 15 times during 0.5s. At each step, it acquires the data by 12samples/cycle. In multi-machine system with three generators, transient stability is assessed at 0.55s.

For the variable dead time control scheme proposed in [1], we are able to distinguish clearly between a transient and permanent fault and estimate the precise secondary arc extinction time using the voltage waveform of the tripped line. In the case of a permanent fault, the avoidance of reclosure would prevent a second shock, thereby preventing the transient stability from getting worse. However, in the case of a transient fault, the secondary arc extinction time may not be equal to the optimal reclosing time presented in section III; thus the reclosing time has to be greater than the secondary arc extinction time as well as equal to the optimal reclosing time with regard to the transient stability.

Fig. 8 shows the adaptive reclosing algorithm where the reclosing operation is changed depending on the fault type and the transient stability. T_V of block ① is the secondary arc extinction time using the method described in section II, T_O of block ② is the optimal reclosing time described in section III, and the transient stability is assessed in block ③ by using the emergency EEAC described in section V(B).

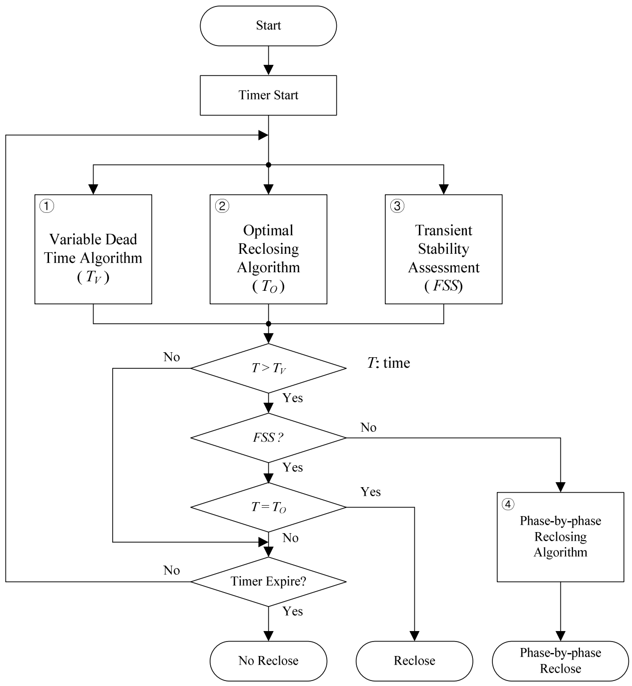

Fig. 8. Adaptive reclosing algorithm

If the stability margin is positive, then the reclosure is activated when T is greater than T_V and equal to T_O. Whereas, if the stability margin is negative then the phase-by-phase reclosing algorithm (block ④) described in section IV is invoked when T is greater than T_V. T_V initially is set to a very large value, so a reclosing command signal to excite the reclosing relay is not generated when a permanent fault occurs.

In the case that the first swing is stable, the reclosure at the optimal reclosing instant enhances the transient stability, whereas in case that the first swing is unstable, the phase-by-phase reclosure described in section IV is required to prevent the loss of synchronism. As soon as a trip signal for circuit breaker operation is generated and the reclosing process is activated, the timer is started, and T of the timer is used in the reclosing algorithm. When the timer expires, a final trip signal is generated and reclosing is prohibited after that time.

6. Simulation and Results

6.1 Multimachine system model

The transmission line may be close to generating station or remote from generating station. The faults at the transmission lines which may be close to generating station have more impacts on the transient stability of power system. Therefore, this paper applies the proposed algorithm to transmission lines which may be close to generating station as shown in Fig. 9. A set of simulation tests were performed on the test model of a 345kV power system

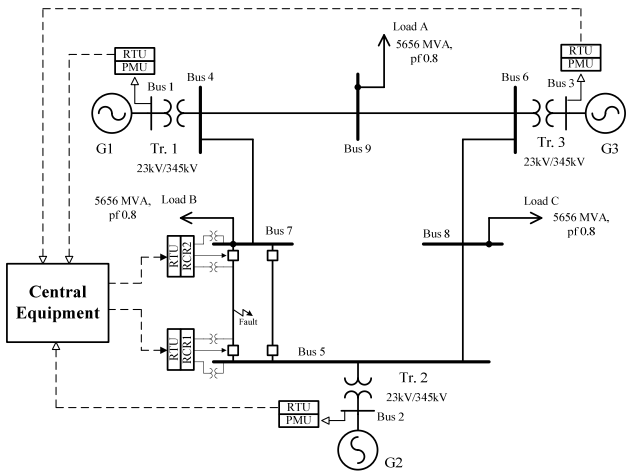

Fig. 9. Model of power system (3 machines and 9 buses system)

shown in Fig. 9, which is the nine-bus system that has three generators and three loads. The pre-fault loading condition of each load in Fig. 9 is 5656MVA, pf. 0.8. This system is interfaced with the model of the reclosure relays implemented through ATP/EMTP MODELS, which makes it possible to simulate the interaction between the power system and the relay [15-16]. Here, the generator model consists of the synchronous machine, governor and excitation system. The transmission line connected between bus 5 and bus 7 is selected as a target line to which a fault is applied. For a transient fault, Johns and Aggarwal's primary arc model [1] is utilized, and the secondary arc is simulated using the technique in [17].

The fault considered is a three-phase fault, which occurs 2s after the start of the simulation at a fault distance of 5km of total line length, which is 100km between bus 5 and bus 7, from bus 5. The faulted line is tripped 260ms after the fault occurs. The phasor measurement units (PMUs) and the remote terminal units (RTUs) are installed at the power station of generators G1, G2 and G3, where the angle and power of the generators are measured and transmitted to the central equipment in real-time via the data transmission system. In the central equipment, the generator angle of the equivalent OMIB is calculated and transmitted to the reclosure relays (RCR1 and RCR2 in Fig. 9). Here, the generator angles may be obtained from the phasor measurements at the generator terminals [13, 14]. The conventional autoreclosure relay, and the adaptive relay that adopts the proposed adaptive autoreclosure algorithm, are simulated individually, and their performances are compared.

6.2 Simulation results

This paper simulates the transient faults according to various initial angle of G2. In the transient stability assessment (block ③ of Fig. 8) of the adaptive reclosing algorithm, the transient stability is predicted by using the

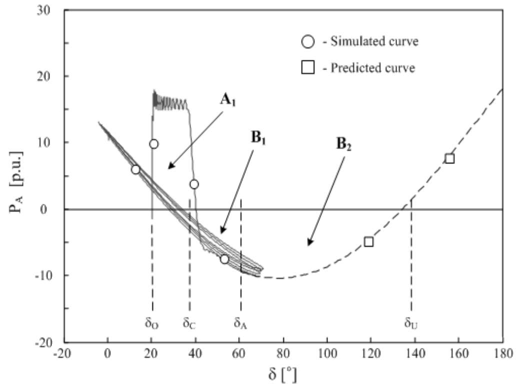

Fig. 10. Simulated and predicted power angle curves when the fault is cleared 260ms after it appears (Initial generator angle of G2 is 20°)

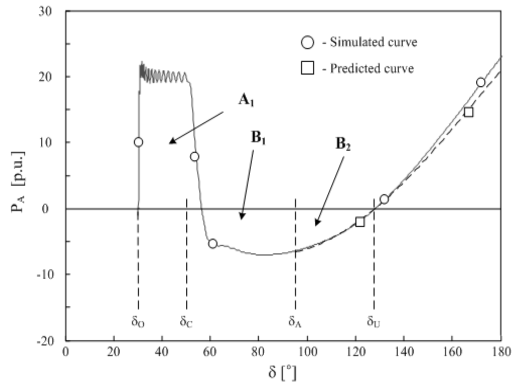

Fig. 11. Simulated and predicted power angle curves when the fault is cleared 260ms after it appears (Initial generator angle of G2 is 30°)

Table 1. Transient stability margins for some initial generator angles

Initial generator angle (G2)	A_1	B_1+B_2	η_1	η_2	Stability
10[deg]	48.05	1679.54	33.95	1631.49	FSS
15[deg]	74.95	942.68	11.58	867.73	FSS
20[deg]	114.53	626.31	4.47	511.78	FSS
30[deg]	263.14	180.73	-0.31	-82.41	FSU

generator angle of the equivalent OMIB. Figs. 10 and 11 show the simulated (in EMTP) and predicted power angle curves in cases when the first swing is stable and unstable, respectively. In the simulation of the transient stability assessment (block ③ of Fig. 8) of the adaptive reclosing algorithm, the generator angles δ are recorded from δ_O to δ_A, where δ is increased to δ_A, and δ_A is the angle after a delay time of 0.5s for transient stability assessment after fault clearing. At δ_A, the P_A-δ curve is predicted, and the areas A_1, B_1 and B_2 are calculated using the generator angle from δ_O to δ_A. Then, the transient stability is predicted by comparing area A1 with area (B_1+B_2). Table 1 shows the areas A_1 and B_1+B_2 and transient stability margins according to the initial angle of G2, where the initial angle of G1 and G3 is 0° and 5°, respectively. When initial angle of G2 is 30°, the stability margin is negative, so the first swing is predicted to be unstable.

Fig. 12 depicts the generator angle of the equivalent OMIB, which is calculated in the central equipment. Here, the initial angles of G1, G2 and G3 are 0°, 10° and 5°, respectively. The line is reclosed 0.4s after the tripping of the circuit breakers in the case of conventional reclosure, and 1.13s after in the case of adaptive reclosure. As can be seen from Fig. 12, oscillation of the generator angle can be reduced by applying the proposed adaptive reclosing scheme although reclosing time of conventional reclosure is faster than that of adaptive reclosure. It, therefore, can be said that the proposed scheme can improve the transient stability of system.

Fig. 13 depicts the generator angle of equivalent OMIB, which is calculated in the central equipment. Here, the initial generator angles are 0°, 30° and 5° of G1, G2 and G3, respectively. Unlike the other cases, the first-swing of this case is predicted to be unstable, so the phase-by-phase reclosure algorithm is invoked according to the adaptive reclosure algorithm. As seen in Fig. 13, the angle attains a stable state by employing the adaptive reclosure. The generator angle returns to stable state because the phase-by-phase is performed. However, when the conventional reclosing scheme is applied, generator angle diverges rapidly which means that system can't no longer keep stable state. Hence, it is obvious that the proposed scheme can be effective under the circumstance where the generator angle is high.

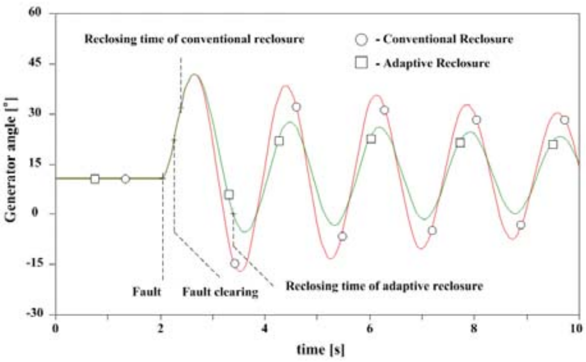

Fig. 12. Generator angle of equivalent OMIB when the tripped line is reclosed after the fault clearing (Initial angles of G1, G2 and G3 are 0°, 10° and 5°, respectively).

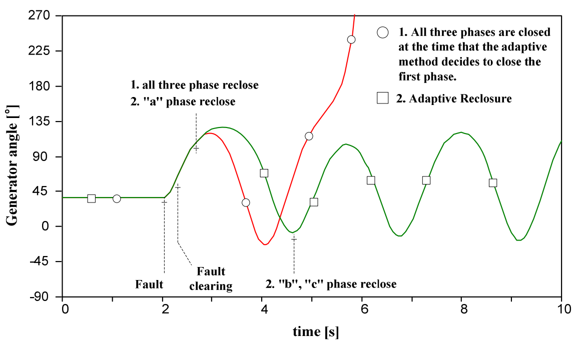

Fig. 13. Generator angle of equivalent OMIB when the tripped line is reclosed after the fault clearing (Initial angles of G1, G2 and G3 are 0°, 30° and 5°, respectively).

Table 2. Transient stability margins at the instant of post-reclosing

Initial generator angle(G2)	Conventional Reclosure		Adaptive Reclosure	
	η_1	η_2	η_1	η_2
10[deg]	183.31	1493.05	244.02	2355.98
15[deg]	116.78	1161.33	145.69	1656.54
20[deg]	46.23	847.78	77.44	1027.68

Table 2 shows the transient stability margins at the instant of post-reclosing of the conventional reclosure and the adaptive reclosure according to the initial generator angle, and the transient stability margins are assessed using (7). As can be seen, the stability margins are larger when using the adaptive reclosure than when using the conventional reclosure.

To test the validity of the proposed algorithm under various circumstances, a large number of simulations were performed with varying fault distance for each generator initial angle. The fault location is changed by 5km from bus 5 in each case. To demonstrate the superiority of the proposed algorithm, the energy of the angle oscillation is measured using (8).

$$Energy(t) = \int_{t-T}^{t} angle(t)^2\, dt \tag{8}$$

And then,

$$Energy(T) = \int_{0}^{T} angle(t)^2\, dt \tag{9}$$

where *angle(t)* means the generator angle of equivalent OMIB and T=10sec.

Fig. 14 shows the energy of the angle oscillation according to fault distance when the initial angles of G1, G2, and G3 are 0°, 10° and 5°, respectively. Fig. 15 shows the energy of angle when the initial angles of G1, G2, and G3 are 0°, 20° and 5°, respectively. In these cases, the transient stability is maintained. We can find that the energy of the angle oscillation using the proposed scheme is smaller than that in the conventional scheme.

Table 3 shows the energy of angle oscillation at t=10sec in (8) according to fault distance when the initial angles of G1, G2, and G3 are 0°, 30° and 5°, respectively. When the fault distances are 5km, 10km, and 15km, the transient stability is not maintained by the conventional scheme, though it is maintained by the proposed scheme.

Additionally, the energy of the angle oscillation using the proposed scheme is smaller than that in the conventional scheme. The superiority of the proposed scheme can be demonstrated by the simulation results in Fig. 14, Fig. 15 and Table 3.

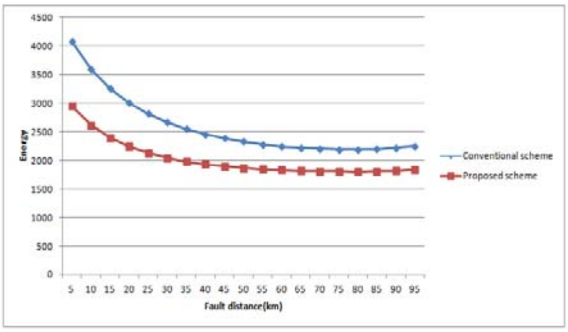

Fig. 14. Energy of angle oscillation according to fault distance (the initial angle of G1, G2, and G3 are 0°, 10° and 5°, respectively)

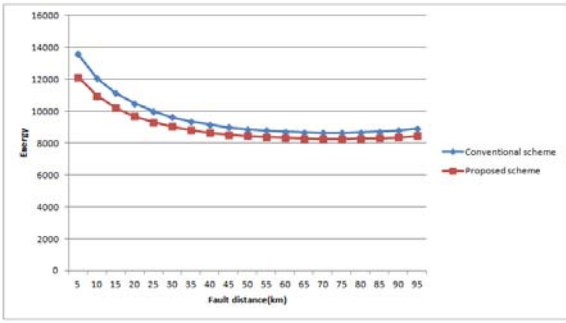

Fig. 15. Energy of angle oscillation according to fault distance (the initial angle of G1, G2, and G3 are 0°, 20° and 5°, respectively)

Table 3. Energy of angle oscillation according to fault distance when the initial angle of G1, G2, and G3 are 0°, 30° and 5°, respectively

fault distance (km)	Conventional scheme		Proposed scheme	
	stable or unstable	Energy	stable or unstable	Energy
5	unstable	144600000	stable	51987
10	unstable	1991200	stable	41191
15	unstable	52524	stable	32334
20	stable	41859	stable	28052
25	stable	34250	stable	25572
30	stable	30447	stable	23978
35	stable	28141	stable	22894
40	stable	26642	stable	22134
45	stable	25575	stable	21575
50	stable	24812	stable	21160
55	stable	24279	stable	20864
60	stable	23906	stable	20649
65	stable	23676	stable	20514
70	stable	23570	stable	20447
75	stable	23596	stable	20453
80	stable	23747	stable	20532
85	stable	24102	stable	20717
90	stable	24647	stable	21010
95	stable	25577	stable	21498

7. Conclusions

An adaptive autorelcosure scheme for improving system stability has been presented. The proposed reclosure method includes variable dead time control, optimal reclosing time, and a phase-by-phase reclosing algorithm. The variable dead time control scheme was used to clearly distinguish between the permanent and transient faults, and the optimal and phase-by-phase reclosure schemes were employed to prevent transient instability. Equally important, the scheme has the ability to maintain transient stability under severe conditions such as monotonic increment of the generator angle following a disturbance. The proposed technique is the reclosing algorithm which is possible to assess the transient stability in real-time by measuring the phasor using PMU. PMU acquire 12 samples / cycle and it transmits them at an interval of 0.033s.

The simulation results show that the fault types (a permanent fault and a transient fault) are classified accurately by using the variable dead time control scheme. Furthermore, the system oscillation is reduced and the transient stability is maintained by using the proposed adaptive reclosure method. Therefore, it is substantially possible to implement the proposed technique in real-time.

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