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Setting of Synchronism Check Phase Angle using Three-Steps Method

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Contents

1. Introduction

1. Most of faults occurring in transmission system → **transient faults**
   → disappearing in a short time

2. **Automatic reclosing :**
   economic and effective method to improve the reliability and transient stability of power system by reclosing the tripped line after predetermined time

3. **Synchronism check**
   checking a synchronism between two separated systems

4. **Synchronism check conditions :** (1) Difference of frequency
   (2) Difference of voltage magnitude
   (3) Difference of voltage phase angle (crucial one)

5. **Standardized conservative setting : 20~30[deg]**
   But, it may be not a good idea especially where the lines are in proximity to generation plant (there might be very large angle separation between the lines)

1. Introduction

※ Example for emphasizing necessity of synchronism check relay

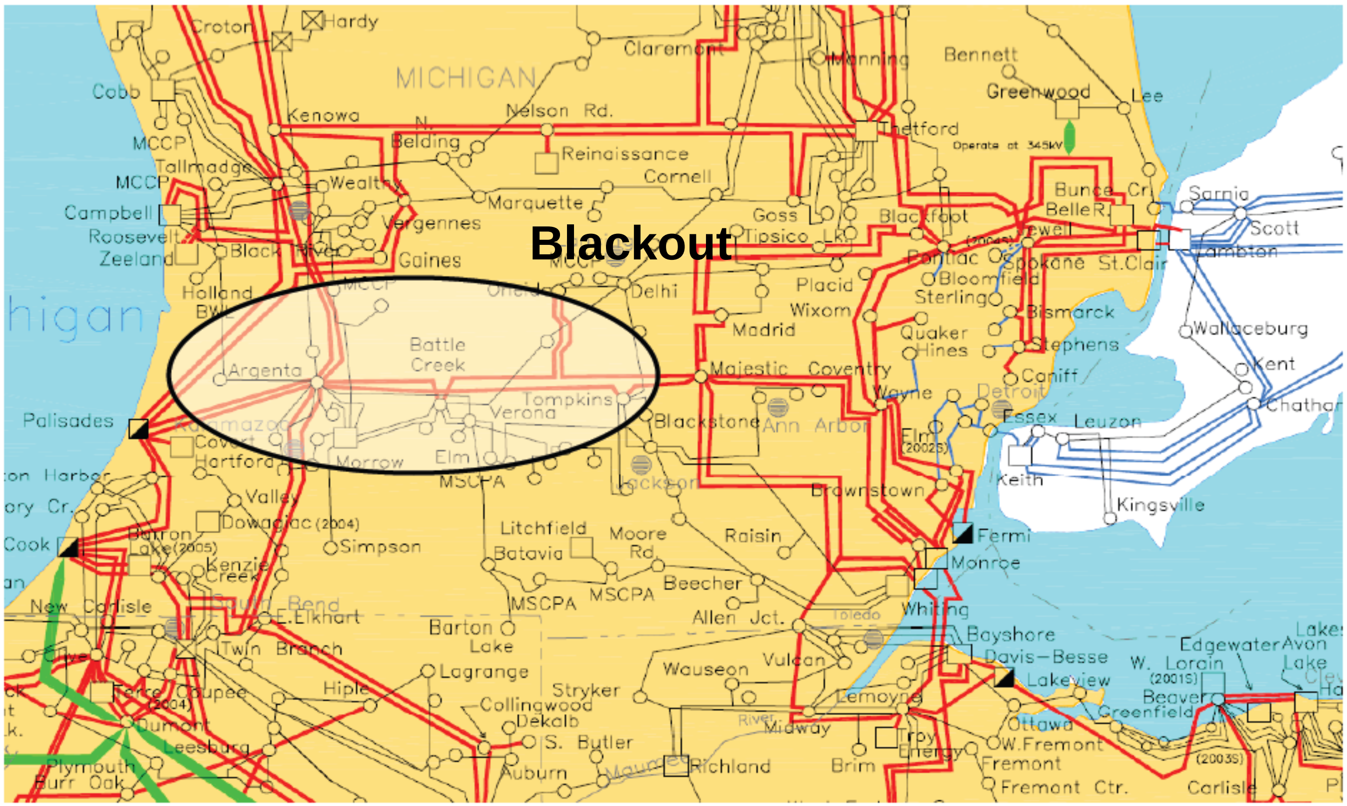


Fig. 1 Transmission system in South-Central Michigan(2003)

- Tripping line between Argenta and Battle Creek → phase angle difference of 80[deg]
- High speed autoreclosing without supervision of phase angle → reclosing failure → blackout

2. Synchronism Check Phase Angle (SCPA)

- **Synchronism Check (to check the synchronism between two systems)**
  - Limiting the impact associated with automatic reclosing **under Live-Bus/Live-Line(LBLL) conditions**
  - Three conditions (associated with the voltage phasors on either side of the open circuit breaker)
    - **Difference of frequency, voltage magnitude, voltage phase angle**

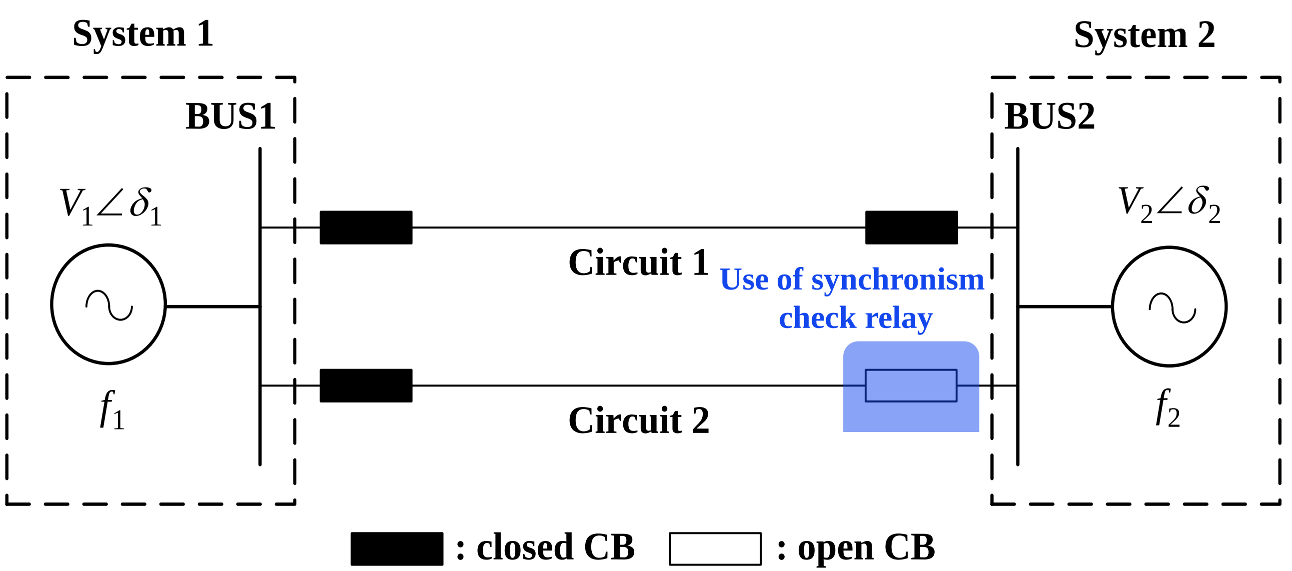


Fig. 2 Equivalent circuit for two systems to be reconnected

3. Deriving SCPA using 3 steps method

3.1 Step 1; Deriving SCPA considering system condition

- System study → A kind of **contingency study** (e.g. lines out, fault, disturbance …)
- **Evaluating a range of system conditions** to identify the worst potential system impact
- Important to find out a **maximum possible angle under credible operating conditions!!**
- **Various factors should be considered in system study (as critical factors)**

→ **changing system conditions** (e.g. angle separation)

① Lines out (should be considered in automatic reclosing situation)

② Generation level

③ Load level

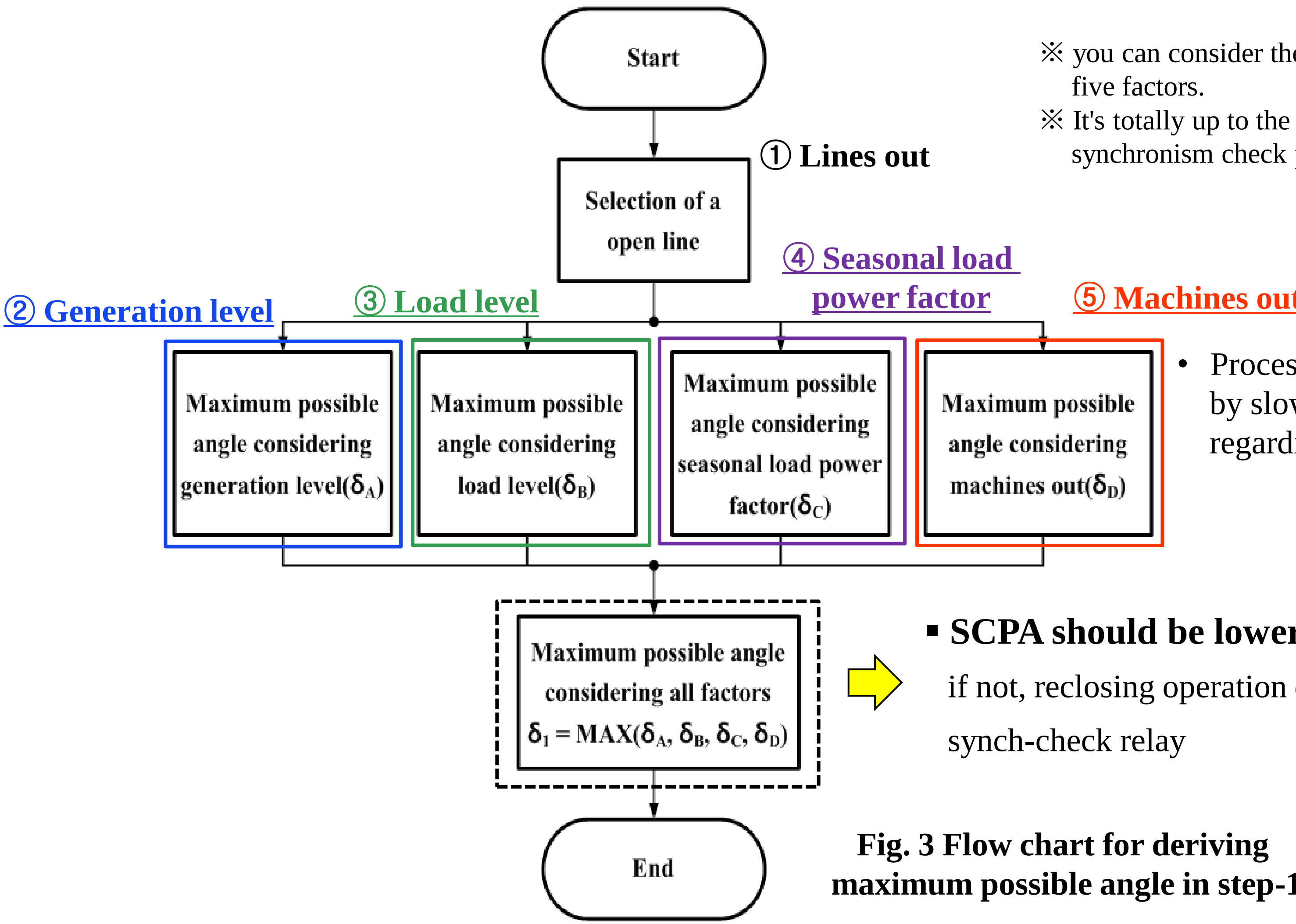
④ Seasonal load power factor

⑤ Machines out

Related to flow of active power

3. Deriving SCPA using 3 steps method

3.1 Step 1; Deriving SCPA considering system condition (Cont.)



※ you can consider the other factors besides these five factors.

※ It's totally up to the engineer who wants to set synchronism check phase angle

- Process is conducted iteratively by slowly changing conditions regarding four factors

▪ **SCPA should be lower than δ_1!**

if not, reclosing operation can't be controlled by synch-check relay

Fig. 3 Flow chart for deriving maximum possible angle in step-1

3. Deriving SCPA using 3 steps method

3.2 Step 2; Deriving SCPA considering impact on turbine generator

- **Damage on Turbine Generator**
  - Caused by fault, switching operation and sub-synchronous resonance, etc.
  - Disturbances in electrical system → torsional stress on turbine generator

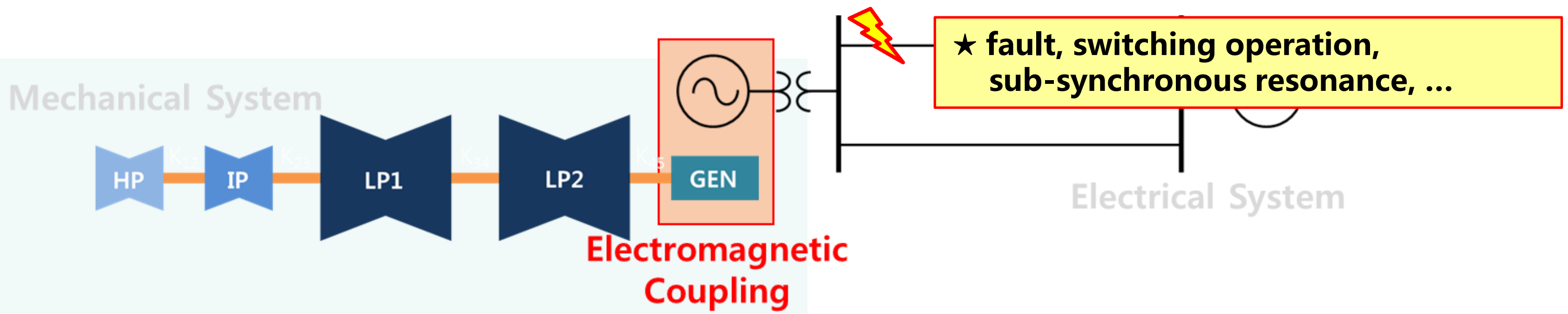


Fig. 4 Electromagnetic coupling between mechanical system and electrical system

- IEEE Committee's recommendation (Screening guide)
  - "**ΔP value equal to 0.5 per unit is considered an acceptable screening level for evaluating steady-state switching** if a turbine generator is operating under the allowable load condition"
  - **Phase angle difference causing over 0.5 per unit of ΔP is not allowable when reclosing**

3.2 Step 2; Deriving SCPA considering impact on turbine generator (Cont.)

- ΔP (sudden power change)
  - ‘Power output at the instant of switching’ - ‘initial power output of the unit’

$$\Delta P[p.u.] = \frac{P_{pre} - P_{post}}{S_{MVA}} \quad (1)$$

※ S_{MVA} : rated power of unit

- Shaft Torsional Torque (imposed by reclosing)

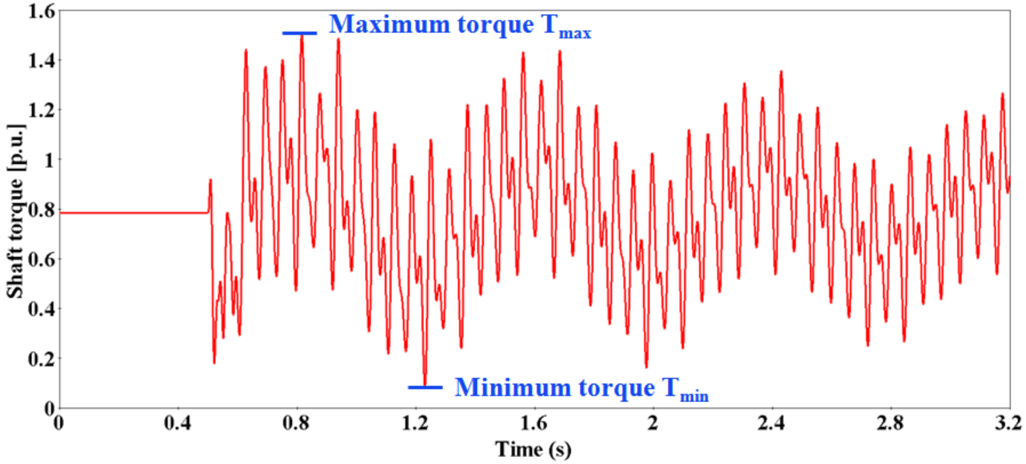


Fig. 5 Shaft torque generated between GEN and LPB

※ Generally, checking out the torque between GEN part and LP part
→ it is normally the largest one among all of torques.

3.2 Step 2; Deriving SCPA considering impact on turbine generator (Cont.)

- **δ_2** → maximum possible angle that can **result in ΔP less than 0.5 per unit** in reclosing the line (Screening guide)
- determined through an **iterative process** until getting **δ_2** like the step-1

※ **α** is an index for representing the **degree of accuracy** and if α is small, it suggests high accuracy of a process

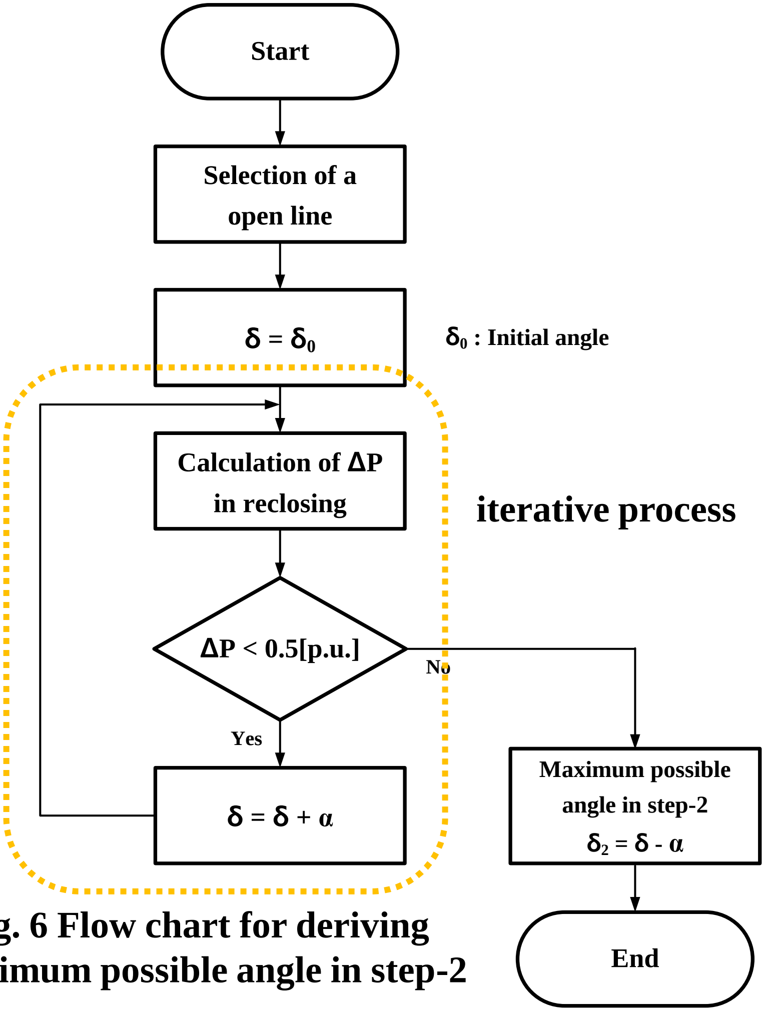


Fig. 6 Flow chart for deriving maximum possible angle in step-2

3. Deriving SCPA using 3 steps method

3.3 Step 3; Deriving SCPA considering impact on system stability

- δ_3 → maximum possible angle which can **make system restored normally** **without any problem on system stability**
- determined through an iterative process like the step-2
- **Integral Square Error (ISE)** is used to check the system restored safely
  - one of the assessment methods for system performance

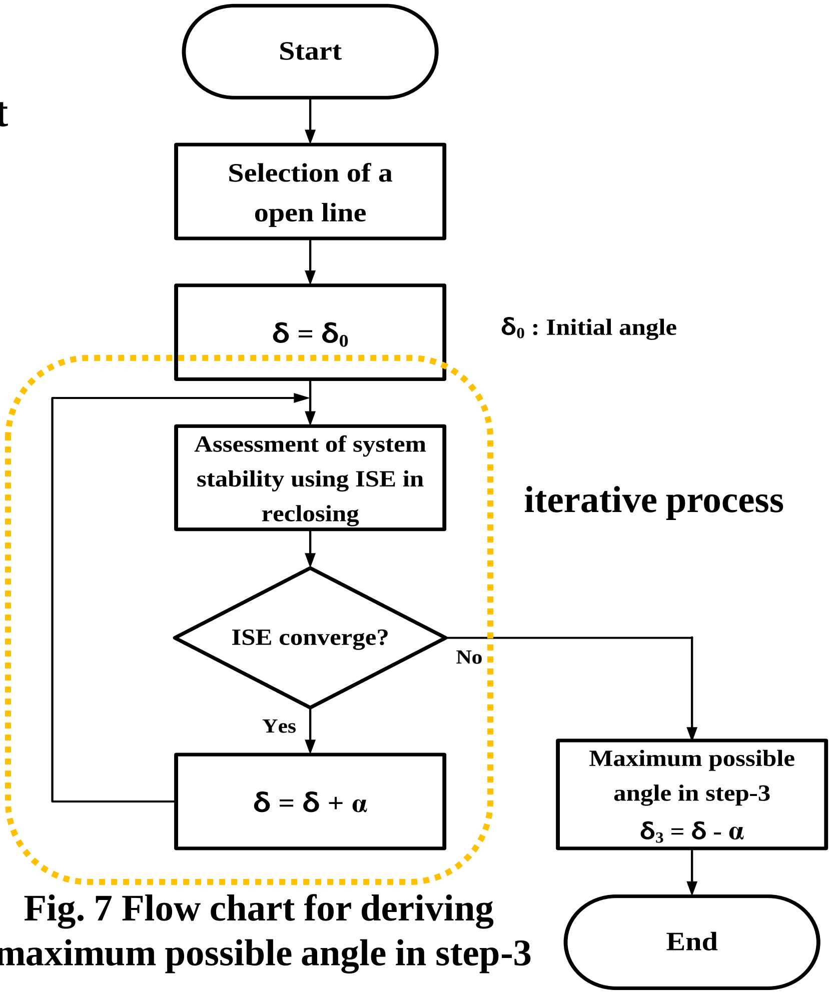


Fig. 7 Flow chart for deriving maximum possible angle in step-3

3. Deriving SCPA using three steps method

3.3 Step 3; Deriving SCPA considering impact on system stability (Cont.)

- Integral Square Error (ISE)

$$ISE = \int_0^T (y(t) - y(\infty))^2 \, dt \tag{2}$$

  - *y(t)* → instantaneous angle across an open circuit breaker
  - *y(∞)* → convergent angle after reclosing (constant)

- *y(t)* is divergent → **ISE also becomes divergent (system got unstable)**

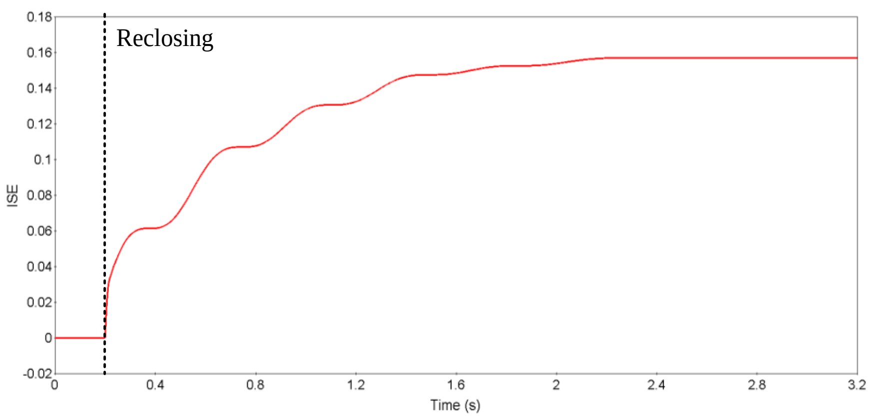


Fig. 8 ISE curve in case of system stable

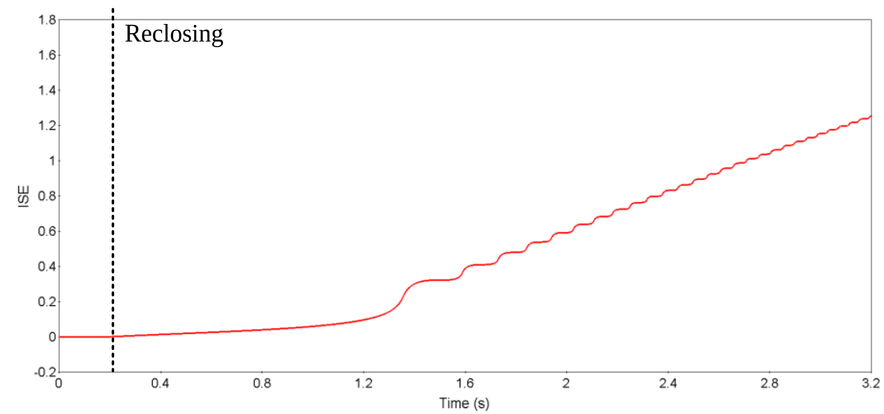
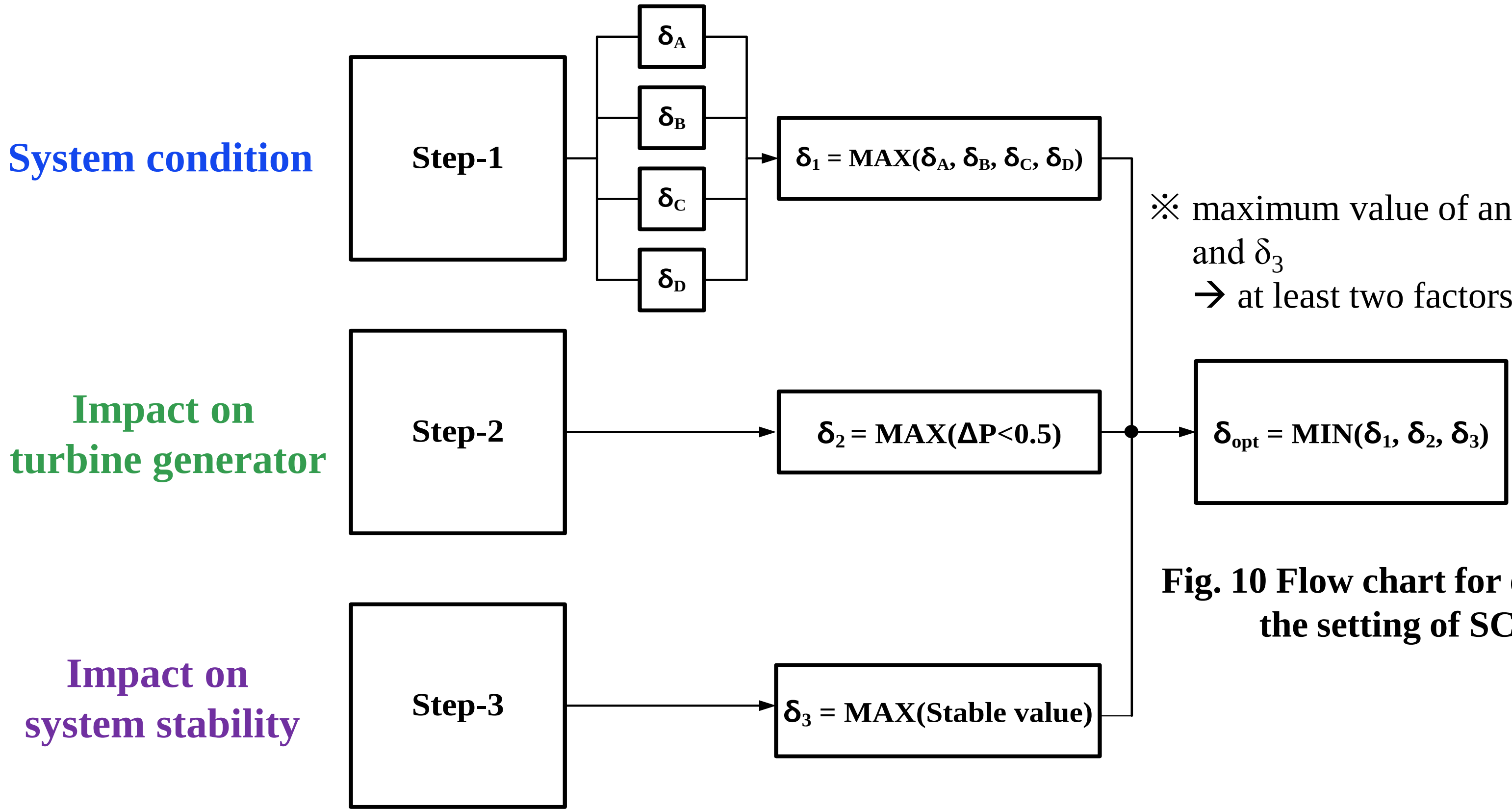


Fig. 9 ISE curve in case of system unstable

3.4 Setting of SCPA using 3 steps method

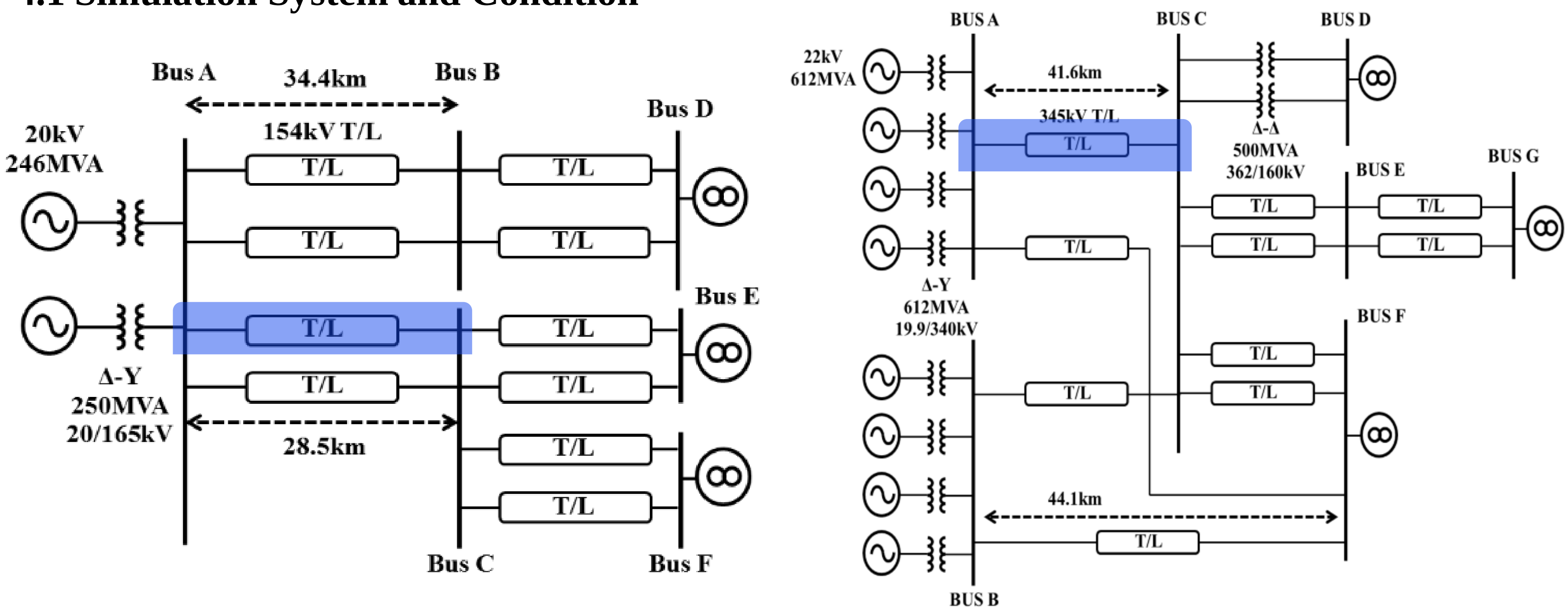
- Setting of SCPA → **minimum value of angles among δ_1, δ_2 and δ_3**
- Covering all the considerations at step-1, step-2 and step-3



※ maximum value of angles among δ_1, δ_2 and δ_3
→ at least two factors are not satisfied

Fig. 10 Flow chart for obtaining the setting of SCPA

4.1 Simulation System and Condition



(a) 154kV transmission system

(b) 345kV transmission system

Fig. 11 Simulation system

- **System is under LBLL condition (one line out situation)**
- Open lines considered are the ones between BUS A and BUS C in both systems (154kV and 345kV)

4. Simulation

Table 1. Parameters of the turbine generator in 154kV

Parameter	value
Rated Power[MVA]	246
Number of poles	2
Moment of inertia [$lb \cdot ft^2 \cdot 10^6$]	HP = 0.009032 IP = 0.015130 LPA = 0.083480 LPB = 0.085970 GEN = 0.084440 EXC = 0.003327
Spring constant [$lbf \cdot ft \cdot 10^6$]	HP-IP = 10.988 IP-LPA = 19.883 LPA-LPB = 29.622 LPB-GEN = 40.335 GEN-EXC = 1.6064
Fraction of external torque[%]	HP = 30, IP = 26, LPA = 22, LPB = 22

Table 2. Parameters of the turbine generator in 345kV

Parameter	value
Rated Power[MVA]	612
Number of poles	2
Moment of inertia [$lb \cdot ft^2 \cdot 10^6$]	HP = 0.018358 IP = 0.030748 LPA = 0.169690 LPB = 0.174740 GEN = 0.171634 EXC = 0.006762
Spring constant [$lbf \cdot ft \cdot 10^6$]	HP-IP = 22.334 IP-LPA = 40.414 LPA-LPB = 60.210 LPB-GEN = 81.985 GEN-EXC = 3.2651
Fraction of external torque[%]	HP = 30, IP = 26, LPA = 22, LPB = 22

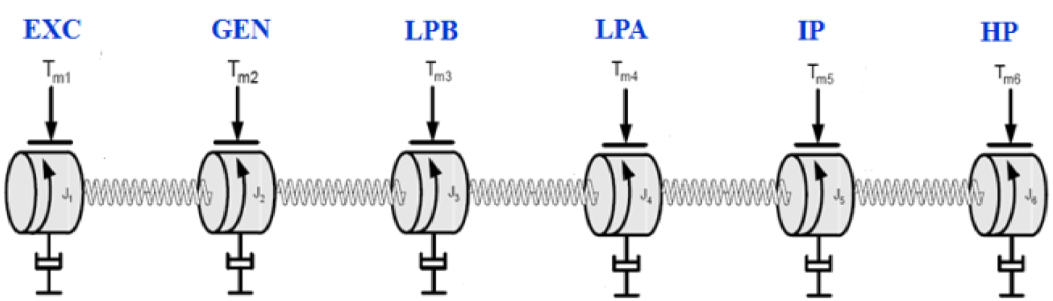


Fig. 12 Multi-mass model of the turbine generator used in transmission system

※ The parameters shown in Table 1 and 2 are based on the physical dimensions of the shaft system and its material properties.

※ Multi-mass model should be used to determine the shaft torsional torque between masses

4. Simulation

4.2 Simulation Result and Analysis

Table 3. Simulation result in step-1 (154kV)

Factors considered in step-1										
Generation level		Load level (power factor : 98%)			Seasonal load power factor (Active power : 450MW at 98%)				Machine out (total number : 2)	
Initial angle of a-phase in generator [deg]	Maximum possible angle [deg]	Active power [MW]	Reactive power [MVAR]	Maximum possible angle [deg]	Season	Load power factor [%]	Active power [MW]	Maximum possible angle [deg]	Number of machine out	Maximum possible angle [deg]
0	14.3	0	0	27.3	spring	97.6	448.163	31.7	0	27.3
5	18.7									
10	23	150	30	28.8	summer	95.1	436.683	31.5		
15	**27.3**									
20	unstable	300	60	30.4	fall	97.8	449.081	**31.7**	1	**29.1**
25	unstable									
30	unstable	450	90	**31.8**	winter	97.5	447.704	31.7		
35	unstable									

Step-1

- The more severe system condition is, the larger angle separation happens
- **SCPA should be lower than 31.8 [deg] considering system conditions**

4. Simulation

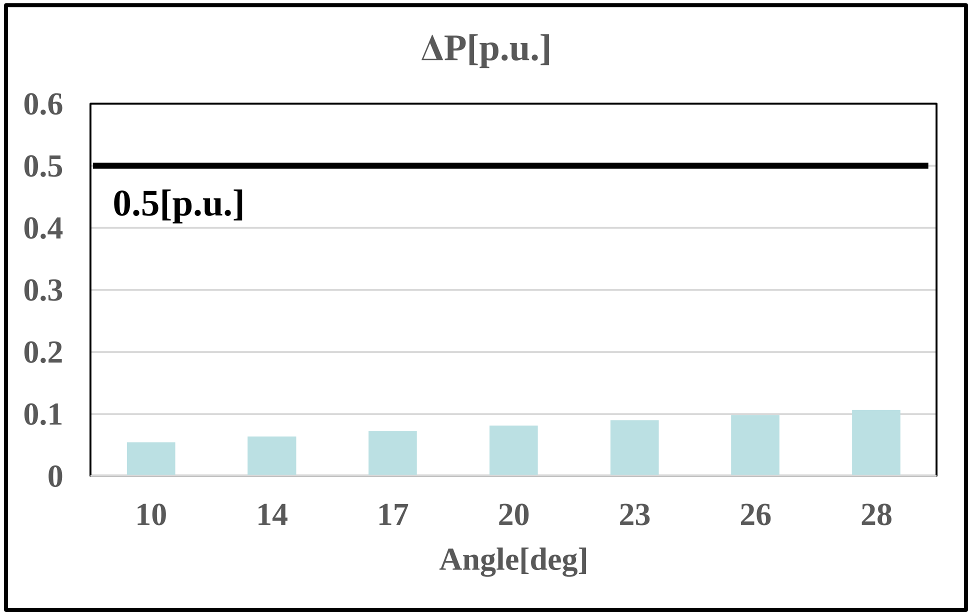


Fig. 13 Simulation result in step-2 (154kV)

Table 4. Simulation result in step-3 (154kV)

Angle [deg]	System stability
15	stable
20	stable
25	stable
30	**stable**
35	unstable

Step-2

- There is no angle separation causing excessive **ΔP**
  → **SCPA can be determined as any value considering damage on turbine generator**

Step-3

- Maximum possible angle in step-3 → 31[deg]
  → **SCPA can be determined as value below 31[deg]**

4.2 Simulation Result and Analysis (Cont.)

- Comparison between simulation result and conventional SCPA in Korea

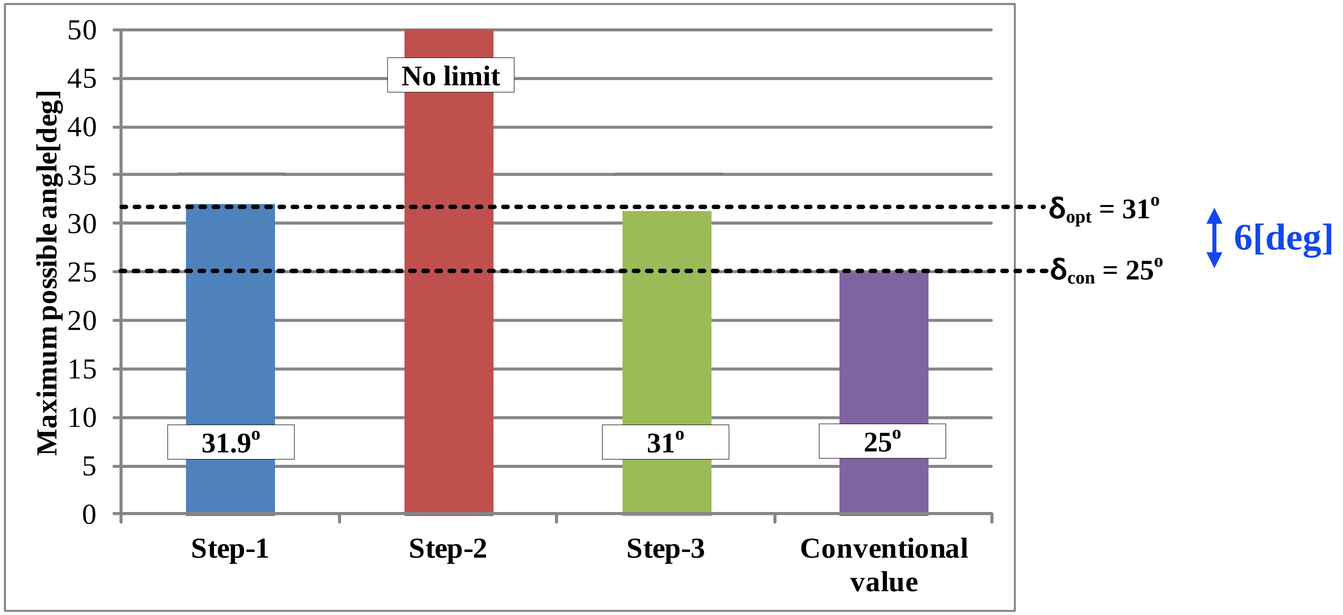


Fig. 14 Comparison between SCPA of 3 steps method and conventional one (154kV)

- Results in 154kV transmission system
  - **Possibility to make the phase angle setting higher** than the angle which is used currently

4. Simulation

Table 5. Simulation result in step-1 (345kV)

Factors considered in step-1										
Generation level		Load level (power factor : 98%)			Seasonal load power factor (Active power : 450MW at 98%)				Machine out (total number : 8)	
Initial angle of a-phase In generator [deg]	Maximum possible angle [deg]	Active power [MW]	Reactive power [MVAR]	Maximum possible angle [deg]	Season	Load power factor [%]	Active power [MW]	Maximum possible angle [deg]	Number of machine out	Maximum possible angle [deg]
20	15.9	0	0	35.9	spring	97.6	448.163	39.7	0	35.9
25	19.5	150	30	37.3						
30	23	300	60	38.6	summer	95.1	436.683	39.4	1	36.5
35	26.6	450	90	39.9						
40	30.2	600	120	unstable	fall	97.8	449.081	39.8	2	unstable
45	33.8	750	150	unstable						
48	35.9	900	180	unstable	winter	97.5	447.704	39.7	3	unstable
50	unstable	1050	210	unstable						

Step-1

- The more severe system condition is, the larger angle separation happens
- **SCPA should be lower than 39.9 [deg] considering system conditions**

4. Simulation

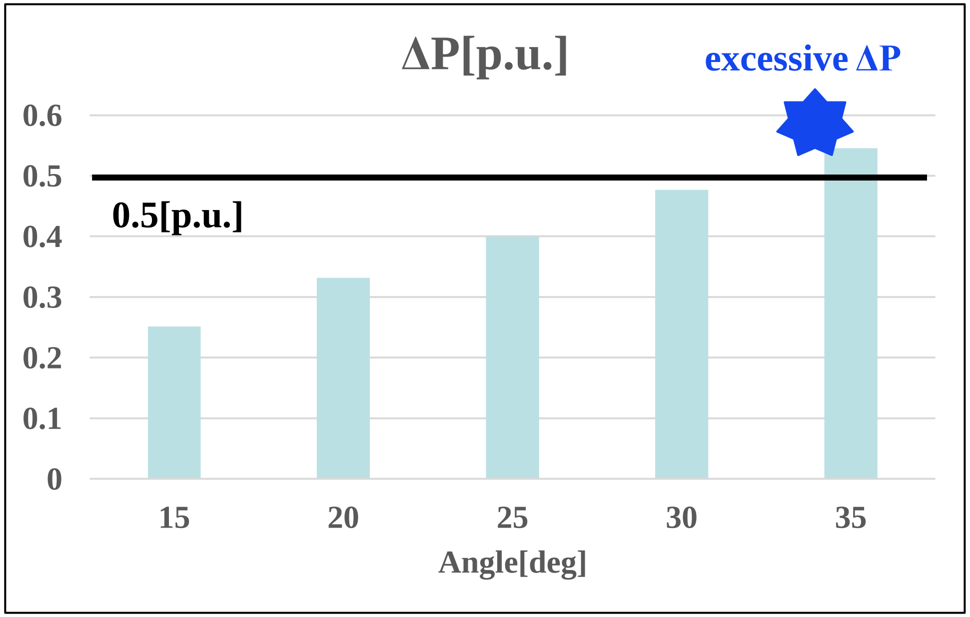


Fig. 15 Simulation result in step-2 (345kV)

Table 6. Simulation result in step-3 (345kV)

Angle [deg]	System stability
15	stable
20	stable
25	stable
30	stable
35	**stable**
40	unstable
45	unstable

Step-2

- There is limitation of angle separation causing excessive **ΔP (32[deg])**
  → **SCPA should be lower than 32[deg] considering damage on turbine generator**

Step-3

- Maximum possible angle in step-3 → 39[deg]
  → **SCPA can be determined as value below 39[deg]**

4.2 Simulation Result and Analysis (Cont.)

- Comparison between simulation result and conventional SCPA in Korea

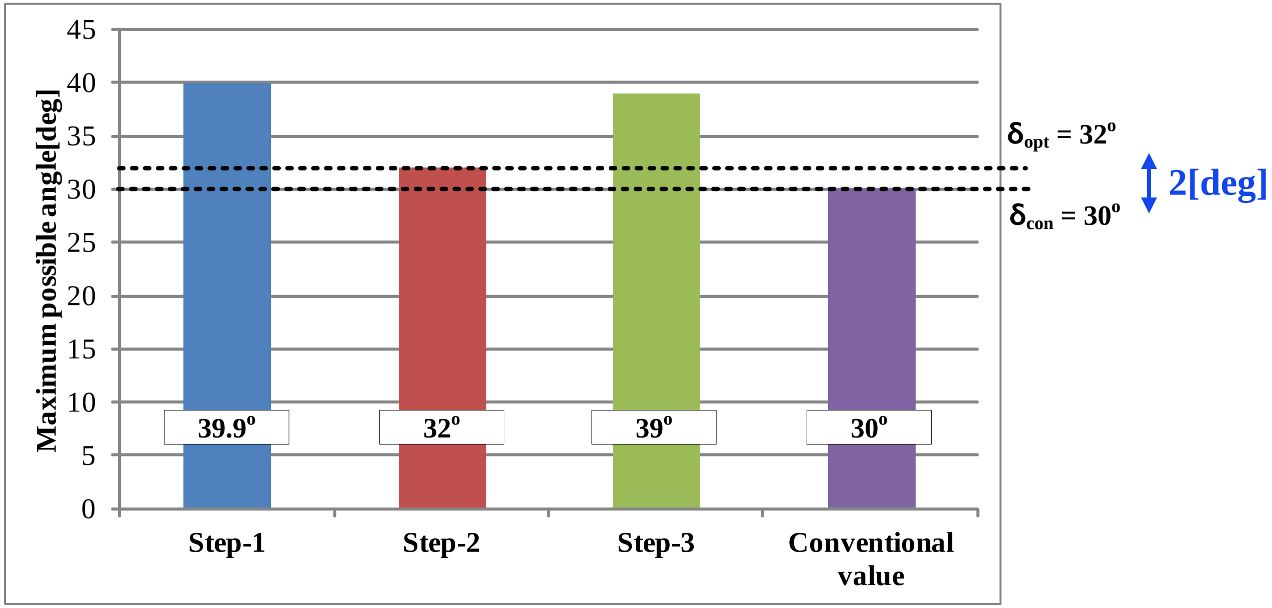


Fig. 17 Comparison between SCPA of 3 steps method and conventional one (345kV)

- Results in 345kV transmission system
  - conventional synchronism-check phase angle setting in Korea is quite **appropriate and reasonable**

5. Conclusion

Setting of Synchronism Check Phase Angle in Transmission Line using System Condition and Damage on Turbine Generator

- **Synchronism check**
  : checking a synchronism between two separated system
- 3 steps method is used by considering follows at each step
  - **System condition** → evaluate a range of system conditions
  - **Damage on turbine generator** → using ΔP as a screening parameter
  - **System stability** → using ISE to check stability of system
- Conventional SCPAs in Korea are evaluated
  - 154kV → **possibility to make conventional SCPA higher**
  - 345kV → **appropriate and reasonable**

Reliable SCPA
→ Solving the problems due to impacts on system

Thank you for listening!

Q&A