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The Interconnection Technology of Small Self-generating System with Distribution Line

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Abstract — The demand of Small Self-generating System (SSS) including Small Cogeneration System (SCS) is constantly increasing with the need of electricity and/or thermal in office, hospital, hotel, and small factory, etc. It is especially recommended to operate SCS in the heat-following mode to maximize the efficiency of generator. In case of the heat-following mode SCS has got to be connected to distribution system so as to send surplus power to the utility or receive the short power from utility. But the interconnection of SSS with distribution system causes a few problems such as the bad power quality, and low security. If SSS is not promptly disconnected after faults occur (Islanding of SSS), it can not only damage equipment of utility and adjacent customers but also endanger life of human due to overvoltage or overcurrent. In this paper it has been deeply discussed if interconnection of engine self-generator/control system satisfies the protective requirement for SSS or not. 500 kW Engine generator running in the Jodo island has been used to perform the analysis of interconnection.

1. Introduction

In recent, our country is carrying out the expand of generating facility, the construction of transmission line, the step-up of transmission voltage to extra high level keeping step with brilliant growth in the field of economy. But we have difficulties in acquiring the land for the construction of generating facility and transmission line. Besides, new construction of thermal or nuclear power plant is more difficult, because they are causing the environmental problem due to CO_2 gas emission. The electric energy of existing thermal power plant is generated in the course of converting the mechanical energy produced from the steam made by boiler. The remaining thermal energy is emitted in the air, which lowers the efficiency of energy (30~40%). If this remaining energy is reused for other purpose, the higher efficiency of energy will be possible. It is expected that cogeneration system can satisfy this requirement. Our country is having a tendency to construct a lots of building needing some thermal and electric energy. Higher efficiency of energy more than 90% can be possible if cogeneration system is used, because co-generation system is reusing the remaining thermal for the heating of building without throwing away. There are three types of operation of cogeneration system (heat-following operation, electricity-following operation, and base load operation). It is desirable to select the heat-following mode to keep the highest efficiency of SCS. So it is necessary to connect SCS to the utility so as to send surplus power to the utility or receive the short power from utility in case of heat-following mode. Even if interconnection of SCS with utility can enhance the whole efficiency, there are some difficulties in interconnection. Interconnection of SSS can cause the lowering of power quality and several security problems. In advanced country they have already interconnection rule for DSG (dispersed generation)[1][2][3]. Our country has also established the Interconnection Guideline of SCS presented through the research report called "Final Report on the Technical Development for the Interconnection of Cogenerator with Distribution System"[4] In that report, crucial protective requirements have been described. In this paper we are going to analyze if the present state of interconnection of 500 kW engine generator is proper in the light of interconnection guideline or not. This engine generator connected to power system is running at the Jodo island. In determining the property of present state of generator/control system, lots of simulation works have been executed with respect to the typical distribution system with conventional protection systems such as over/under frequency relays, reverse power relay, and over/under voltage relays. Islanding, energizations of the de-energized feeder by cogeneration systems, and reclosing problem have been analyzed in the aspect of safety.

In section 2, several of problems have been described in case of islanding of cogenerator.

In section 3, case studies have been performed to analyze the property of present state of Jodo generator/control system. The recommended Interconnection Guidelines for SCS have been described in Appendix.

2. Operation Problems of SSS when Connected to Utility

2-1. Islanding phenomena of SSS

Islanding phenomena is defined that SSS including SCS is at a state supplying line load with its power, in other words, energizing a section of distribution system with SSS isolated from source of power system after faults occur at the adjacent distribution system or in the upper power system. This is possible if the load on the section closely matches the power output of SSS. If this is the case, conventional over/under-voltage and over/under-frequency relays may not detect this abnormal "islanding" condition.

A. Safety

This is a dangerous situation for utility personnel, because they might assume that the section is deenergized if they are not aware of SSS on the distribution feeder or if they assume that SSS is no longer energized when it actually is energized. Among bad effects due to islanding, there are the reverse-charging of isolated line, excessive phase difference and large fault current/frequency/voltage variation. Besides, if "islanding" condition is not cured, security problem, such as an electric shock of operator and a destruction of electric equipment will take place. The reverse-charging of isolated line is meaning that line between cogenerator and an opening point, which should be deenergized, is energized due to an inadvertent switching or specific phenomena like an accidental agreement between power output of SSS and load. A phase difference may exist if recloser tries to reclose line at first time after recloser opens line due to some faults. If this phase difference is excessive at the time of reclosing and the disconnection system for protection does not work properly, large fault current will enter into distribution line, which destructs a power facility and endanger life of human.

B. Power Quality

Connection of SSS to the distribution system can affect the quality of power delivered to loads and the operation of distribution system equipment. Power quality refers to the admittable voltage and frequency variation band. KEPCO (Korea Electric Power Cooperation) requires customers to maintain voltage with respect to low-voltage & extra-high voltage in the rule 25 of electric utility rule as follows.

Admittable frequency range is also specified in the rule 43 of electric supply rule as follows.

2-2. Operation of reclosing

Automatic reclosing system is used for the line protection. There are the surface flashover of porcelain insulator, contact of tree or birds in the type of faults of transmission line. Once these faults happen, faults will be got rid of if recloser trips line and line becomes no-voltage. Especially, the more reclosing time is short, the more the probability of continual power transmission is high. This processing is called "Automatic Reclosing System".

Table 1. Admittable range of voltage.

Standard Voltage		Voltage Range
Low voltage	110 V	110 V±6 V
	200 V	200 V±12 V
	220 V	220 V±13 V
	380 V	380 V±38 V
Extra-high voltage	22.9 kV	22,800 V~23,800 V
	154 kV	~172 kV

Table 2. Admittable frequency range.

Standard frequency	Frequency Range
60 Hz	60 Hz±0.2 Hz

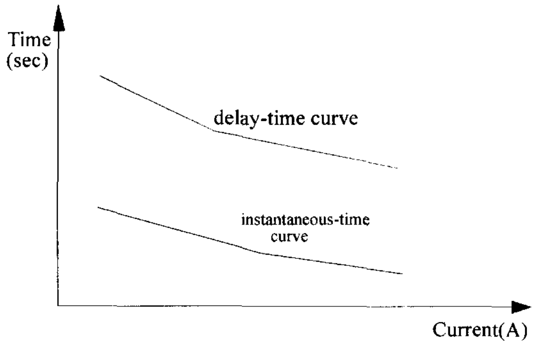


Fig. 1. Typical characteristic curve of recloser.

The automatic reclosing system has some functions identifying an instantaneous fault and a permanent fault, the operation of these function follows the characteristic curve of recloser (Fig. 1).

In case of electronic type, if fault current flows into line, bushing CT detects this current, and then breaker is opened automatically.

Figure 2 is showing the working sequence of recloser (2F2D. instantaneous:two times, delay:two times) In the Fig. 2, ①&② are representing instantaneous action, ③&④ are representing delay action whose exact times are determined by the characteristic curve of recloser in Fig. 1.

Reclosing time corresponds to ⓐ (period of no-voltage), which gives a time an instantaneous fault can disappear. Most of Korea distribution system consists of 22.9 kV except for 6.6 kV a few areas that are still adopting. Table 3. is showing the reclosing time of distribution system.

If SSS is connected to 22.9 kV feeder and the

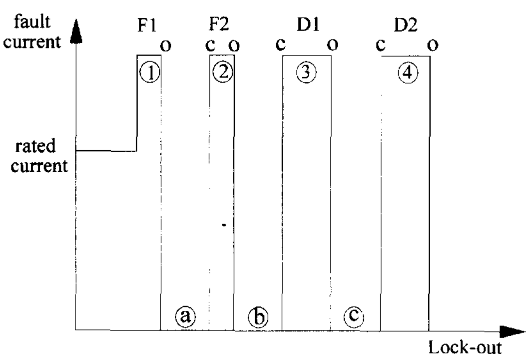


Fig. 2. Typical working sequence of recloser.

Table 3. Reclosing type of Korea distribution system.

Voltage grade	Reclosing time & times
22.9 kV	• totally underground line: 0 time • ratio of underground line≥30%: 1 time (0.5 sec) • ratio of underground line<30%: 2 times (0.5 sec, 15 sec)
6.6 kV (Overhead line, Underline groundline)	• 2 times reclosing (0.5 sec, 15 sec)

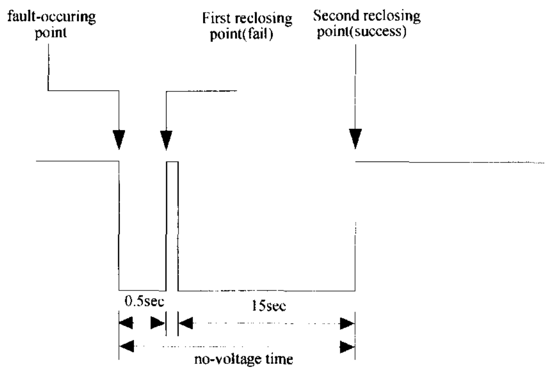


Fig. 3. Operating sequence of recloser (22.9 kV).

ratio of underground of distribution line which is connected by SCS is less than 30%, the operating sequence of recloser in Korea is like Fig. 3.

AS SSS will be connected to 22.9 kV feeder in the future, it is desirable to consider carefully the reclosing sequence like Fig. 3 when an operation of recloser is planned. Recloser installed in the 22.9 kV distribution line should act according to Fig. 3 in case faults occur. If faults occur with SSS connected, interconnection-breaking system should act within 0.5 second as the first reclosing time of recloser is set to 0.5 second. Otherwise recloser acts properly, large fault current will enter into customer or utility side, and destruct power facility if the phase difference is got wider at the instant of reclosing. If it is impossible to disconnect SSS assuredly, it is recommended to install the deadline supervision deferring the operation of recloser.

3. Case Study

3-1. Construction of sample system

Let's assume a sample distribution system (Fig. 4)

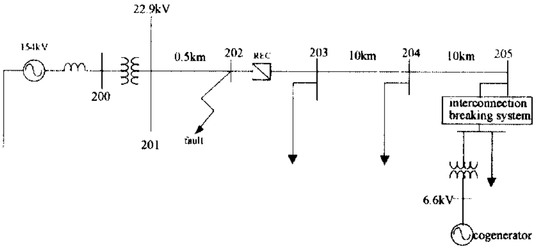


Fig. 4. Sample distribution system for the interconnection analysis of SSS.

connected by SSS through 3ϕ Δ-Y transformer (22.9 kV/6.6 kV) and interconnection breaking system to carry out the interconnection analysis of SSS when faults happened nearby.

This sample system is composed of an infinite bus, 22.9 kV transmission line, 3ϕ transformer, constant impedance load, and 500 kW Jodo engine generator.

3-2. Input data for system analysis

3-2-1. Generator input data (GENSAL)

We selected the Jodo engine generator (500 kW, cosθ=0.8) as SSS and generator data is as follows.

T'_{do}=2.0 T''_{qo}=0.04 H=0.342 D=0 X_d=0.8285 X_q=0.62 X'_q=0.1351 X''_d=0.0924 X_l=0.08 S(1.0)=0.1 S(1.2)=0.4

Most of generator data came from the manufacture data sheet except for H (inertia) which is derived by the following formula.

$$H = \frac{\text{stored energy at rated speed MW sex}}{\text{MVA rating}} \quad (1)$$

$$H = 5.48 \times 10^{-9} \frac{J(RPM)^2}{\text{MVA rating}} \text{ [sec]}$$

$$= 5.48 \times 10^{-9} \frac{12.0668 \times 1800^2}{0.625} = 0.342 \quad (2)$$

3-2-2. Line data

Distribution line is assumed to be ACSR 160 mm², neutral line 95 mm². Overhead line is represented by the lumped RL parameters coupled mutually. And the value of positive parameter is 3.86+j7.42 [%/km] based on 100 MVA.

3-2-3. Excitation system data

Most of small engine generators are adopting brushless excitation type requiring less maintenance cost. The apt mathematical model for this excitation type is EXAC1, and block diagram (Fig. 5) and model parameters are as follows.

EXAC1
(IEEE Type AC1 Excitation System)

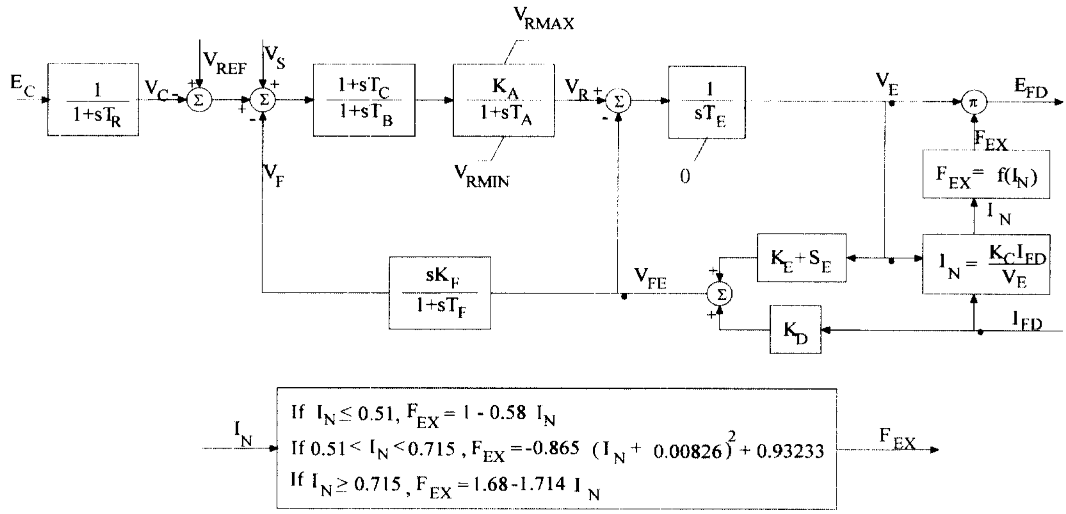


Fig. 5. Block diagram of excitation system (EXAC1).

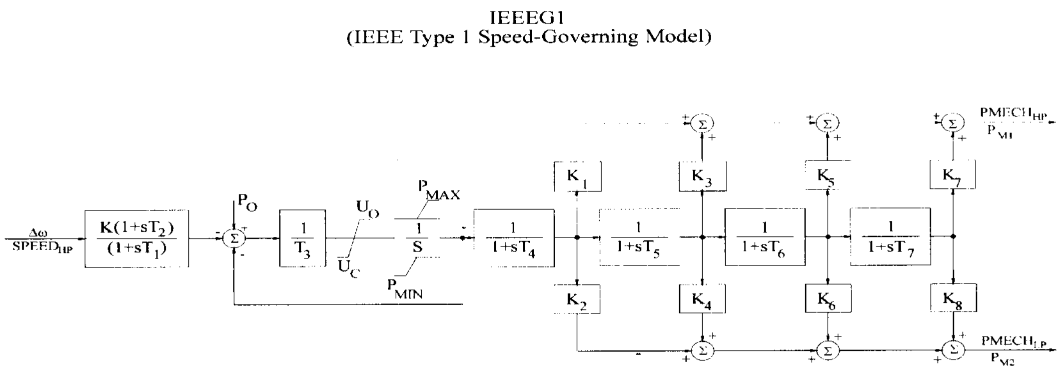


Fig. 6. Block diagram of speed-governing system (IEEEG1).

$T_R=T_B=T_C=0$ $K_A=400$ $T_A=0.01$ $V_{RAMX}=7.5$ $V_{RMIN}=-7.5$
$T_E=1.2$ $K_F=0.035$ $T_F=0.8$ $K_C=K_D=0.2$ $K_E=1$ $E_1=3.64$
$S_E(E_1)=0.03$ $E_2=5$ $S_E(E_2)=1$

3-2-4. Governor-engine model

It is assumed that governor is Woodward PID-type and type of engine is Catapillar. The apt model is selected by IEEEG1 (Fig. 6).

And the values of model parameters are as follows.

$K=10$ $T_1=T_2=0$ $T_3=0.25$ $U_0=2$ $U_c=-2$ $P_{MAX}=1$ $P_{MIN}=0$
$K_1=1$ $K_2=K_3=K_4=K_5=K_6=K_7=K_8=0$ $T_4=0.03$
$T_5=T_6=T_7=0$

In Fig. 6 K is droop, T_3 is governor time constant, and T_4 is engine time constant. The remaining gain and time constants are ignored. U_0 and U_c are rate limits, P_{MAX} and P_{MIN} are position limits. There are isochronous operation, droop operation, and constant power operation in the type of governor operation. It is recommended to adopt constant power operation (droop is infinite, K=0) in case of interconnection operation of SCS because it is easier to disconnect SSS.

3-3. Procedure of Case Study

Table 4. Types of case study.

Case #	Line load (MW)	SSS load (MW)	Power of SSS (MW)	Ratio of Overload (%)
1	0.1	0.5	0.5	20
2	0.2	0.5	0.5	40
3	0.26	0.5	0.5	52
4	0.5	0.5	0.5	100

Four case studies have been performed according to the degree of overload like Table 4.

Procedure of case study

① Simulating at steady-state until 1 second.

② Causing three-phase short at bus 202 for 6 cycle.

③ Opening line (202~203) at 1.5 second considering the operation of recloser.

④Interconnection breaking system will disconnect line (204~205) if voltage and frequency deviate from admittable range like below.

Voltage: 0.8 p.u.~1.2 p.u.
Frequency: 59.5 Hz~60.5 Hz

3-4. Simulation result and analysis

Figure 7 is showing frequency responses and Fig. 8 is showing generator terminal voltage responses. Commercial Power System Simulation Tool called PSS/E[5] has been used in analysis.

(1) Interconnection has been disconnected in 1 cycle after fault occurs as frequency goes over 60.5 Hz. Therefore, islanding of SSS could be surely guaranteed (There was the limit of numerical calculation, i.e., minimum step-size=1/2 cycle. So, It could not be possibile to disconnect interconnection exactly at the instant of 60.5 Hz as Fig. 7).

(2) As overfrequency relay detects overfrequency in 1 cycle after fault, it has been acknowledged that interconnection breaking system does not affect the operation of reclosing.

(3) As interconnection breaking system has been acted in 1cycle after faults, frequency has gone

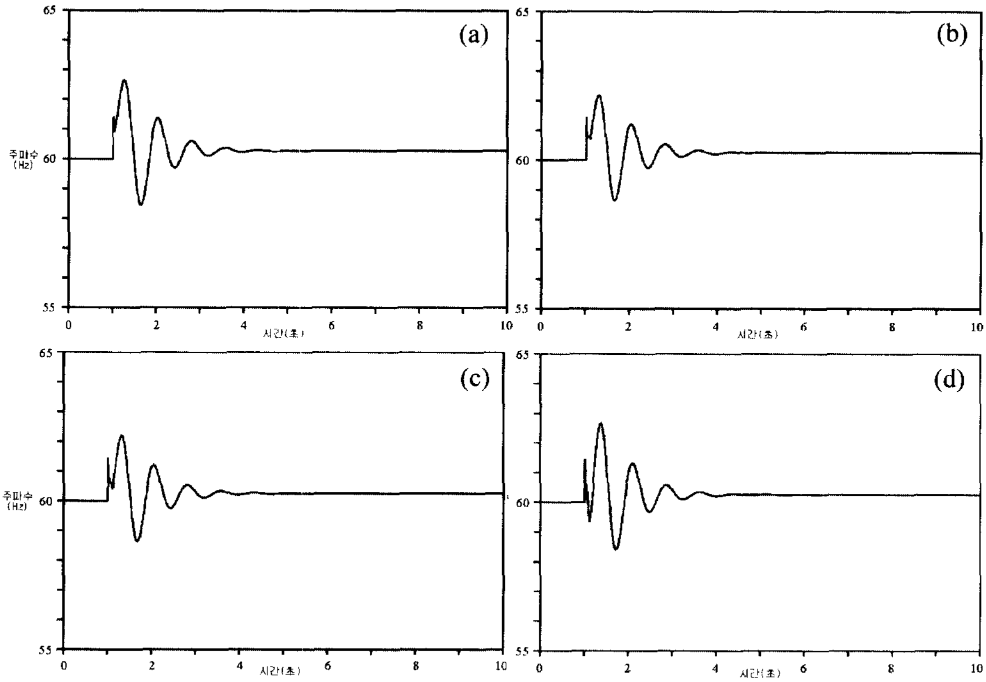


Fig. 7. Frequency response of engine generator.
(a) 20% overload (b) 40% overload (c) 52% overload (d) 100% overload

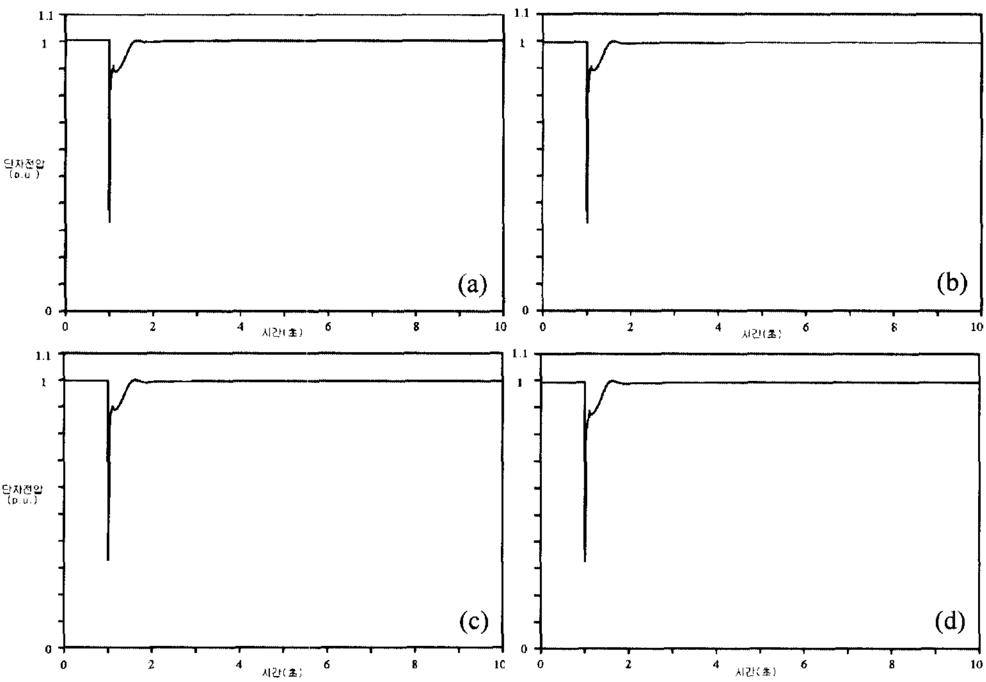


Fig. 8. Voltage response of engine generator.
(a) 20% overload (b) 40% overload (c) 52% overload (d) 100% overload

back to the rated frequency after 4 sec (generation of SSS=load of customer).

As soon as 3-phase fault happends, generator terminal voltage drops instantaneously down near 0.3 p.u. and recovers toward rated voltage very fast after disconnecting the interconnection. This fast voltage response is highly related to the fast-response type of excitation system. We can see that fast response type of excitation system is not proper for the interconnection of SSS as voltage relay may not detect this fast voltage response even though fast voltage response can enhance transient stability in power system. Therefore, it is recommended to select the excitation system such as moderate response type in case of SSS for voltage relay to operate properly.

And voltage responses according to the overload looks like similar. But initial voltages are inclined to decrease as the ratio of overload increases as though the those amounts are relatively small because the capacity of SSS are very small and interconnected with the infinite system.

4. Conclusion

In this paper, we have identified the property of present state of Jodo generator/control system in the light of the Interconnection Guideline of Small Co-generation system through lots of simulation studies. We could have the following contributions.

(1) We have identified that there are no problems in the interconnection of Jodo engine generator with power system when considering the existing interconnection guideline.

(2) It has been identified that engine generator can be easily disconnected by frequency relay (primary protection), considering that frequency response is acute due to its small inertia.

(3) In case of using engine generator as SSS, it has been acknowledged that it does not affect the normal operation of the existing recloser.

Reference

1. PG & E Interconnection Handbook.
2. Eastern Utilities Eastern Edison "Qualified Cogenerators and Small Power Producers".
3. 日本電氣學會, 分散形電原 系統連系技術指針, JEAG 9701-1993.
4. 1998.10, 산업자원부 "소형열병합 발전 계통연계 방안 연구" 최종보고서.
5. PSS/E Power System Simulation Program - Application Manual, Power Technologied Inc., (1987).

APPENDIX: INTERCONNECTION GUIDELINE FOR SCS

Rule 1. (Scope) This guideline is applied to the self-generating electric facility owning SCS whose capacity is below 2,000 kW.

Rule 2. (configuration of protective system) Customer owing SCS must install the interconnection breaking system to prevent itself from islanding, finally to obtain the security and reliability, when several faults occurred in the adjacent area. The configuration of interconnection breaking system is as follows.

① Protective system is composed of the primary and secondary protective relay.

② The primary and secondary protective relay circuit should be separated not so as to interfere with each other. This protective system is called to "fail-safe" protective system. By using "fail-safe" protective system, the more reliable protection is available.

③ The main relay of interconnection breaking system are voltage and frequency relay.

1. Under the admittance of reverse power flow, if accidents such as fault or short occur, frequency relay that is primary protective relay will detect over/under frequency and disconnect SCS. If failed, disconnection should be performed by voltage relay that is secondary protective relay.

2. Under the admittance of reverse power flow, if partial or whole blackouts of upper system happed, underfrequency/undervoltage relay will act in case generation is less than load or overfrequency/overvoltage relay will act in case generation is greater than load.

3. Under prohibition of reverse power flow, if accidents like fault, short, blackout in upper system

occur, it is possible to disconnect SCS by the reverse power relay which detects reverse power flowing from customer to utility. But, if substation breaker opens faster than interconnection breaking system just after accidents, it is impossible to disconnect SCS, as reverse power cannot flow into utility. To prevent this phenomenon, we select primary protective relay as reverse power relay and secondary protective relay as frequency/voltage relay.

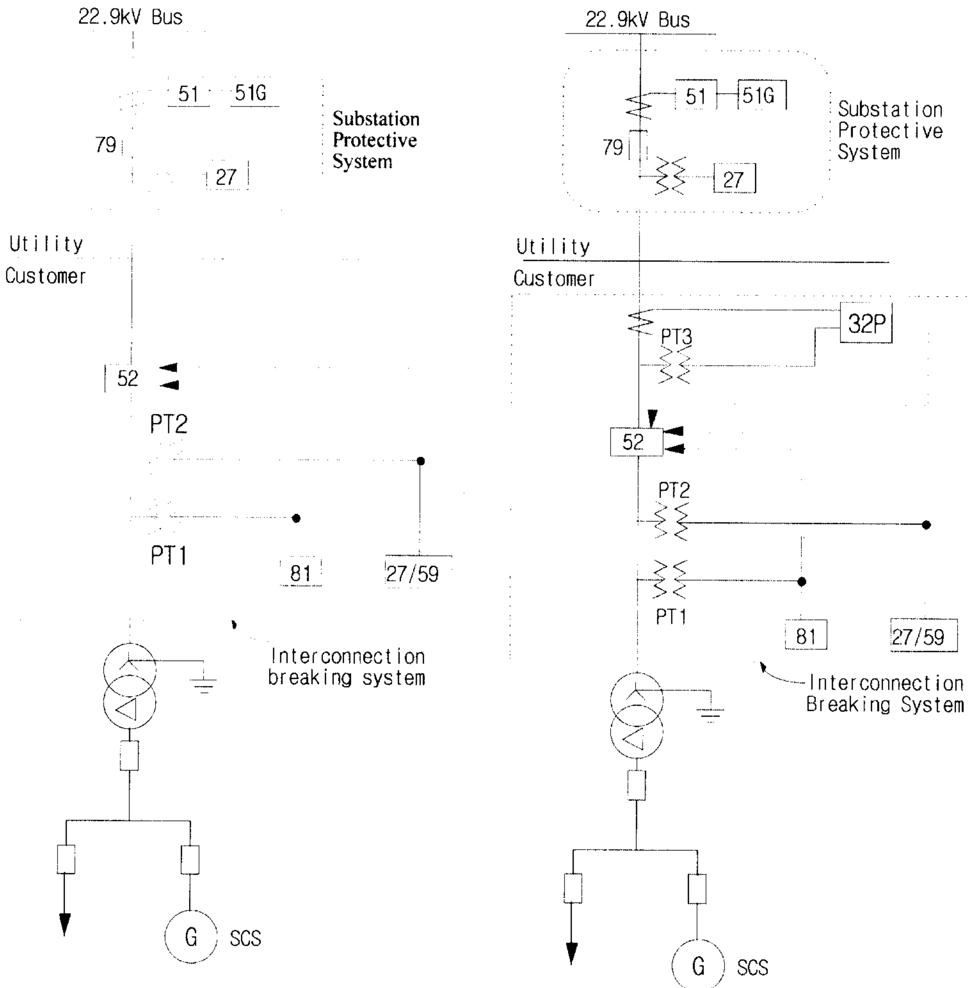
4. The typical configuration of interconnection breaking system in self-generating electric facility owning SCS is like App. Fig. 1.

5. The undervoltage relay is set to act below 0.8 p.u. and overvoltage over 1.2 p.u. Underfrequency relay is set to act below 59.5 Hz and overfrequency relay over 60.5 Hz.

Rule 3. (Operation of Relosing)

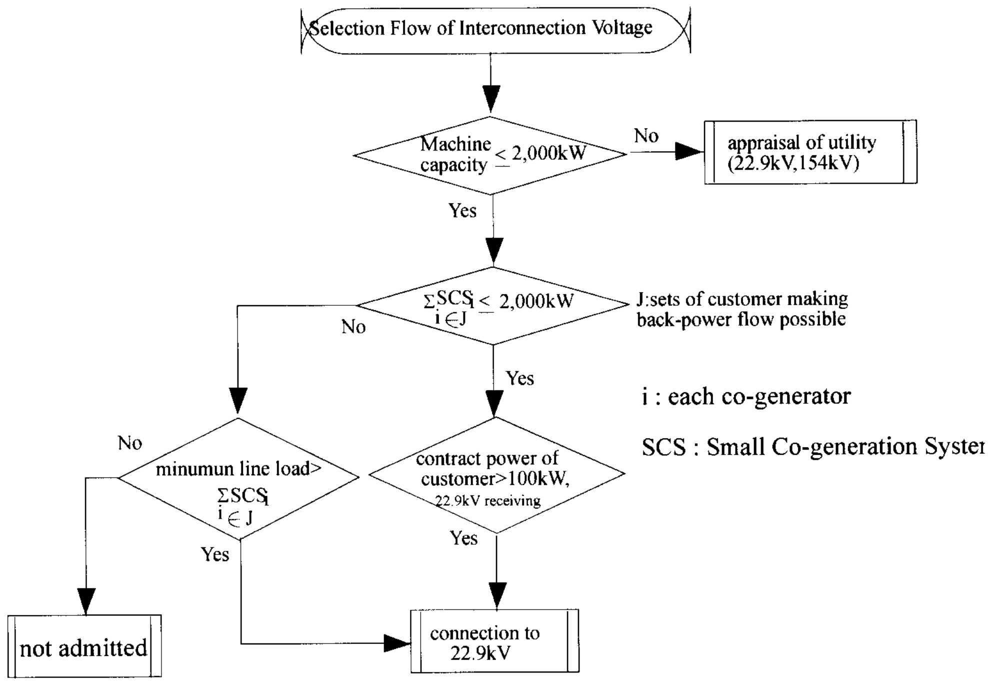
① As the no-load period (reclosing time) of recloser is 0.5 sec in case of 22.9 kV, setting time of protective relay consisting of interconnection breaking system should be less than 0.5 sec to prevent excessive current due to the phase difference.

② In preparation of worst case (it is impossible to disconnect SCS within 0.5 sec), it is recommended to install the deadline supervisor.



(a) Reverse power is admitted (b) Reverse power is forbidden

App. Fig. 1. Interconnection breaking system of SCS.



App. Fig. 2. Flowchart of determination of interconnection voltage.

Rule 4. (Determination of interconnection voltage)

Most of Korea distribution system consists of 22.9 kV line. Reference of determination of interconnection voltage is as follows.

① It must be satisfied the following items to connect SCS with 22.9 kV feeder.

1. Each capacity of SCS should not exceed 2,000 kW.

2. The whole rated capacity of SCSs should be below 2,000 kW with reverse power admitted.

3. Reasonable voltage should be maintained with reverse power admitted.

4. SCS customer should install a current limiter in case if there is any possibility short-circuit current goes over the capacity of circuit breaker.

② Flow chart of for determination of interconnection voltage is App. Fig. 2.