Case Study for Protection Relay System of Small Scale Cogeneration Interconnections

Kap-Koo Yoon, Young-Suk Han, Kyung-Sik Kim

***Abstract*— The Co-Gen System which maximize energy efficiency was installed at the industrial plants at the initial stage. However Small Scale Co-Gen System was expanded even to the general end-users such as housing and building owing to ESCO business recently. For this SSC, inter-connected operation to the utility is desirable due to voltage and frequency fluctuation following to unbalance between power output and load. Then voltage unbalance with utility system, frequency, increase of short circuit capacity, reclosing, and ALTS etc. should be fully considered for the inter-connected operation. Voltage variation, protection coordination, Co- Generators island running, and short circuit capacity should also be solved. For Co-Gen users, the several protection relays are recommended to install at the user's main incoming panel by the guide lines and/or instructions from Utility. The special points of technical considerations during Small Scale Co-Gen Interconnection Setup are hereunder reviewed.**

***Index Terms*-Small Scale Co-Gen system, SSC, Consumer Service Requirements, Protection Theory, Interconnection Configurations, Technical Consideration, Protection and Control schemes.**

I. INTRODUCTION

Small Scale Co-Gen's Status[1] in Korea

A. Type of Small Scale Co-Gen

Engine, Turbine, or Fuel-cell is used usually with Natural gas.

--Gas Engine; supply warm water to building(hotel, hospital, industry)

--Gas turbine; supply steam to industry and building

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--Fuel-cell; not applied as yet because of economical efficiency.

B. Installation

-53 customers' operation

-110 MW Capa, 0.2% of Total Domestic Generation Capability.

**EU; 9% as of year 2001, 18%(target of year 2010).

**U.S.A.; 7% as of year 2000, 20%(target of year 2010).

C. *Propagation Target by year and Anticipated Effects[1] is shown at Table 1*

Table 1. Propagation Target by Year and Anticipated Effects

Year	‘03	‘04	‘05	‘07	‘09	‘11	‘13
Small Scale Co-Gen (thousand KW)	100	116	135	293	623	1,307	2,700
Percentage (%)	0.18	0.20	0.22	0.44	0.84	1.68	3.50
Saved effect (thousand TOE)	-	131	172	344	692	1,390	2,792
Saved effect (thousand US $)	-	328	429	861	1,730	3,475	6,981

In case of propagating 2,700 MW(3.5% of total generation capability and equals to 3 sets of the nuclear power plant by year 2013), total cost is anticipated 7.25 billion

USD and saved effect shall be 667 million USD[1].

II. Establishing Consumer Service Requirements and Supply Methods

The utility-consumer interconnection provides the path for power flow between supplier(Utility) and user(Consumer).
Consumer Service Requirements and Supply Methods shall be established correctly.

A. General Process

The supply method to be selected should satisfy the consumer's load requirements.
Available utility supply options as well as design standards and operating and maintenance practices shall also be considered[2].

B. Consumer defines Requirements

The consumer defines his present and future load requirements.

C. Utility defines Service Availability

Utilities usually publish standard information booklets detailing the requirements for service.
The fact is understood that no electrical utility supply method completely eliminates the possibility of momentary service interruptions or voltages dips.

D. Information Exchange

Once the supply method is established, further exchange of information is required for
-the station design completion

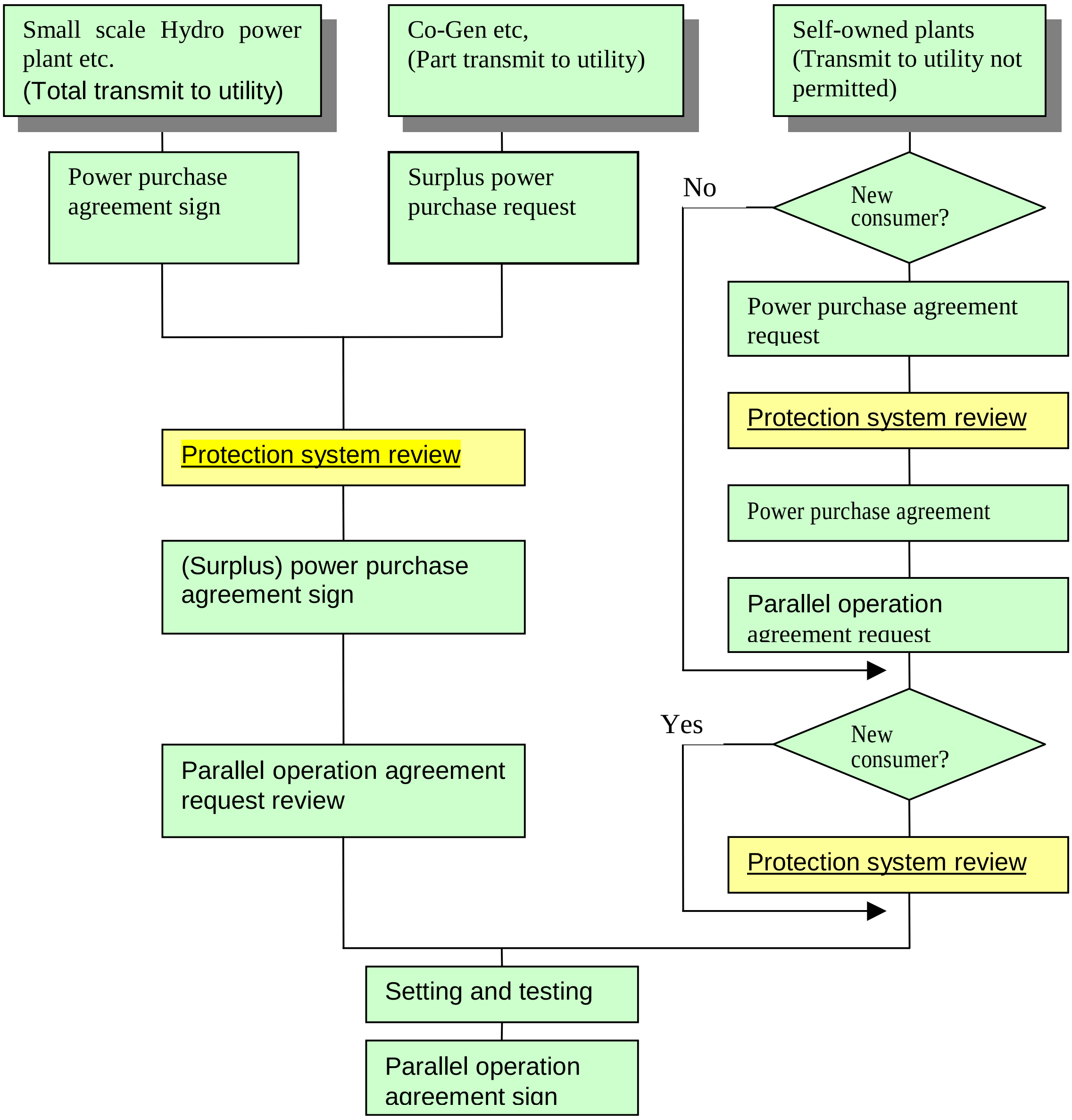


Fig.1 Process flow of work between Utility and Consumer, in case of KEPCO(Korea Electric Power Corporation)

-necessary preparations by the utility to supply the service.

Fig.1 Work flow map between Utility and Consumer in case of KEPCO(Korea Electric Power Corporation).

1) Information Furnished by Utility

- Available short-circuit current-range of single- and three-phase to ground-fault current and associated X/R ratios at the consumer's point of service.
- Operating requirements and restraints.
- Specific protection requirements to coordinate with the utility system.
- Specific reclosing practices on both normal and alternate supply facilities.

2) Information Furnished by Consumer

- Expected service date (when consumer will be ready for power).
- Complete one-line diagram of plant distribution system.
- Preferred supply voltage.
- Transformer ratings, connections, voltage taps, and impedances.
- Power factor correction capacitor ratings and connections.

• Switchgear specifications, including protective relay types and ranges.

• Motor loads, types, sizes, and starting frequency.

• Unusual load characteristics, such as those due to furnaces, thyristors, and other nonlinear loads (include flicker and harmonic producing equipment).

• Generation information, including short circuit information.

III. Reviewing Protection Theory

A. *Protection System Design Considerations[2][6]*

Principle of applying protection relaying system.

• Reliability

.dependability; when operating needed
.security; when operating not needed

• Selectivity

areas to be separated by tripping to minimum as possible.

• Speed

to keep the stability and to minimize damage of equipments.

• Sensitivity

to sense the minimum fault current without supplying capability not restricted.

• Cooperation

neighboring protective device, speed, protection zone should be properly cooperated.

1) Zones of Protection

Relative location of CT and interrupting devices to be carefully considered when designing the protective relaying.

2) Redundancy

(remote)backup protection
dual primary protection

3) Fault Data

Three phase
Phase-to-phase
Double-phase-to-ground
Single-phase-to-ground

4) Fault Current versus Load Current

• Normal load current vs overload current vs fault current

• Case of load current >-fault current
ex, ground-fault current

• Phase over current device should not respond to max load current

B. *Protection System Overview*

1) Circuit-Interrupting Devices

Fuse
Circuit breaker
Switchgear
Source of control power

2) Sensing Devices

CT selection

• Protective relaying CT to be the good characteristics in transient as well as in the steady-state.

• the thermal and mechanical characteristics to be sufficient under the normal and abnormal conditions.

• CT rating, rated burden(VA)

• ratio to consider the saturation

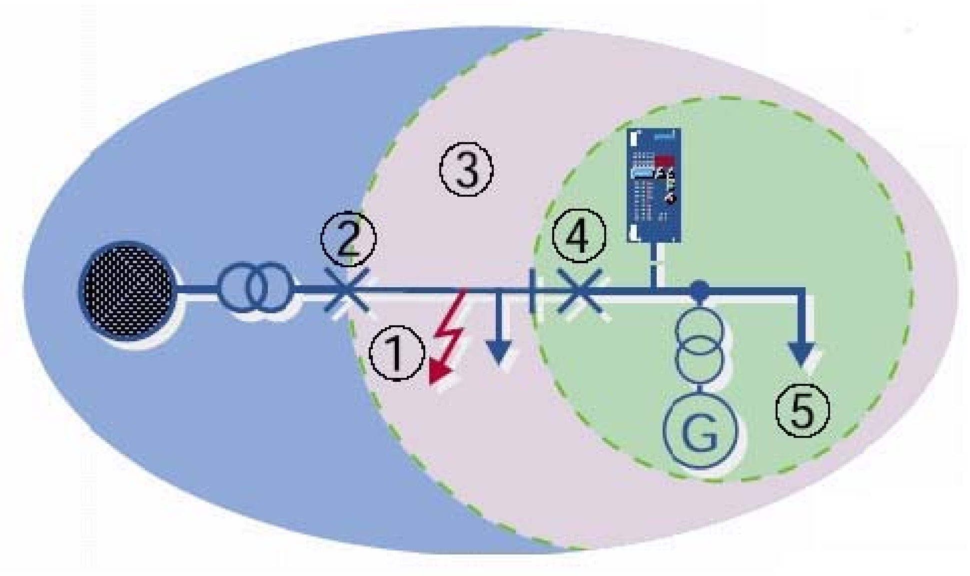


Fig. 2 Synchronizing with mains

PT selection

- the sufficient stability in both steady-state and transient state.

PT rated burden

- suitable installation point to consider protection relay's characteristics.

3) Protective Relaying Schemes[5]

OCR relaying

- Application principle

.the direction of current not changed according to the fault points
.protection coordination considered

- For application

.fault current magnitude
.operating time

Directional OCR relaying

- Application principle

.the direction of fault current being changed.
.the distance of interconnected line too short to apply the distance relays.

- For application

.maximum fault current forward and minimum fault current backward.

Distance relays
Reactive Power protection relay

- the magnitude of fault current too small to apply DOCR System and distance relay
- under minimum capacity of 1 set-generator, the operating of DOCR and/or distance relays are not secure
- fault current ≤ 1.5 x DOCR's setting value

Pilot relaying system

- For the important electric system, when the any fault currents through the whole area of interconnected line should be removed swiftly.
.Voltage differential
.Directional
- Applicable to 22.9kv 2 feeder's interconnected line.

'No Voltage Checking Device' installation.

- to escape asynchronous operation due to reclosing and manual CB operation.

As shown in Fig 2, when synchronizing any kind of generator with the grid network② there are need to protect both systems against possible network faults ①. If the mains fails Co-Gen users can end up with an unintentional grid island ③ supplied by the generator which is no longer synchronized with the mains[4].

Often the mains voltage will return without warning due to an auto recloser operation which can cause damage to the generator and grid system. In order to protect against this relays will rapidly detect any failure in the grid and isolate the generator from the grid island ④. This enables the generator to supply the loads connected ⑤ and prevent any danger of returning asynchronous mains voltage. with the conventional under and over voltage and frequency protection, a fast loss of mains detection using either vector surge or rate of change of frequency (ROCOF) methods, is used with vector surge detection, the phase angle of each individual voltage is supervised and if a phase shift greater than the relay setting occurs, the relay will trip. This voltage phasor shift is a typical characteristic of generators when the grid, which is under load, fails.

• In case of current flow in reverse toward utility not permitted, this can be laid apart on condition that [Dual Protection Relaying System] and [Dual Anti-Island Operating Device] are installed.

• Anti-Island Operating Device means the protection devices to sense the island operating of generator.

• The second relay among 'Dual Anti-island Operating Device' include the 'vector surge relay(78)' or equivalent etc.

Consumer-Owned Generation

• Protection of generator itself to comply with ANSI standards or equivalents.

• Protection and control schemes applied to interconnection to allow for all acceptable modes of operation.

• Be able to detect on the utility system and in the interface substation.

• Be insure that the consumer is promptly disconnected from a faulted circuit.

IV. System Studies for Interconnection

A. Types of Studies

-Short-Circuit study
-Stability study
providing fault current magnitude;
.Required clearing time data
.Data for proper selection of equipment such as
current transformers
interrupting devices
protective relays
.Data for calculating the setting of protective devices
-Load flow
-Transient analysis study
-Special study for under-frequency relay

B. Required Data

-Positive, negative, and zero-sequence impedance values of each system elements. including generators, transformers, and cables etc.
-Transient and sub-transient reactance for generators and synchronous motors.

C. Performance of Studies

Are conducted with computers using generalized application software such as
EMTP
SKM(Power Tools for Windows)
EDSA

PSS/E

Power System Blockset with Matlab

Etc.,

Regardless of who performs the study, any results impacting upon the design or operation of the interconnections shall be clearly communicated to the other party.

V. UTILITY-CONSUMER INTERCONNECTION CONFIGURATIONS

A. Typical configuration

The typical configurations for utility and consumer interconnection are shown in Fig 3 to Fig 9.

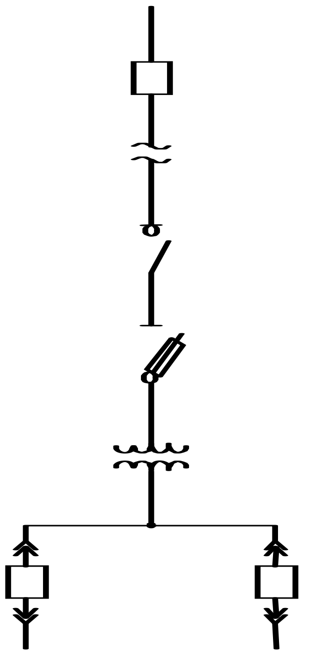


Fig. 3 Single Supply-Single Transformer (transformer with high-side fuse)

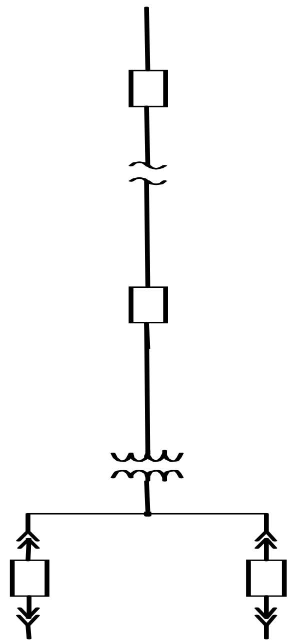


Fig. 4 Single Supply-Single Transformer (transformer with high-side breaker)

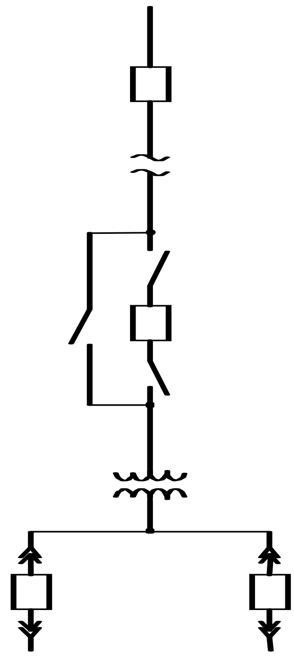


Fig.5 Single Supply-Single Transformer (transformer with high-side breaker and bypass switches)

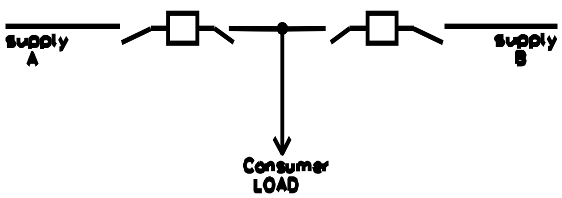


Fig. 6 Dual Supply-Single Transformer (manually operated load break switches)

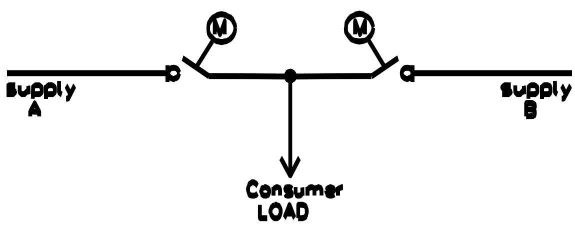


Fig.7 Dual Supply-Single Transformer(motor-operated load break switches)

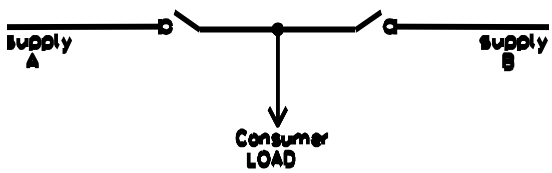


Fig. 8 Dual Supply-Single Transformer(Circuit breakers)

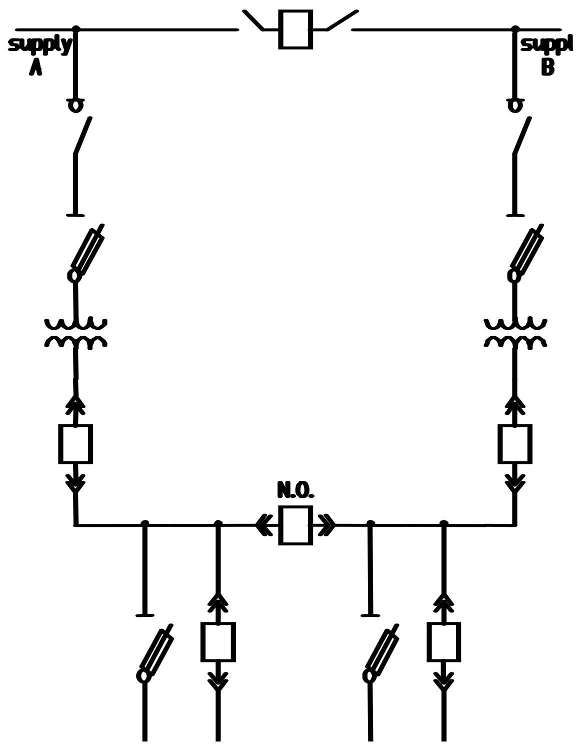


Fig. 9 Dual Supply-Dual Transformer(single-supply circuit breaker)

B. Examples of Standard Protection Relay System of KEPCO[3]

Fig.10 and Fig. 11 below indicate Radial common-use distribution lines in Korea.

22.9kV bus

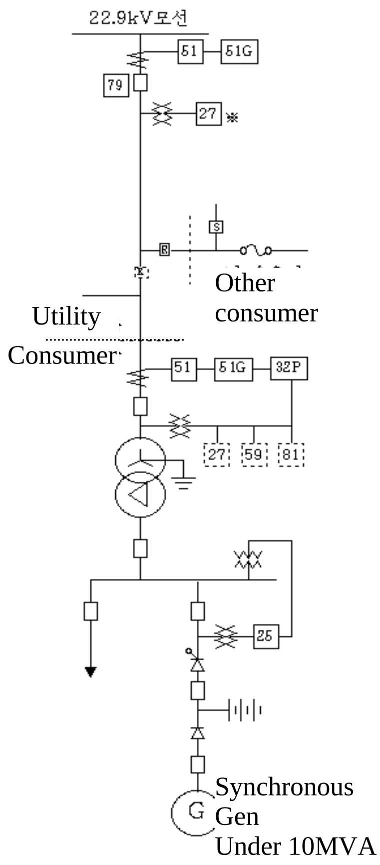
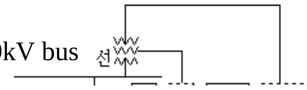


Fig. 10 Radial common-use distribution line #1



① Case of interconnection to D/L line with multi consumers

② Utility 51, 51G : applicable when protection coordination is difficult at utilities bus fault(3Ø, 1Ø)

③ Utility 67, 67G : applicable when 51, 51G mis-operation in some apprehension at utility’s bus fault

④ Utility 27 : against reclosing and asynchronization.

※ when 27 relay installation is difficult, ‘No voltage check ce’ sh alled at Utility S/S or ‘Dual Protection Relaying System’ at consumer side.

Utility

Other consumer

Consumer

⑤ 79 : Two times of reclosing applied

⑥ 32Q : Short-circuit, ground fault protection(3Ø)

⑦ Consumer 27 : Checking device of 32Q mal-functioning and backup protection of three phase short-circuit fault

⑧ 32P : Applicable to consumer who was not permitted to transmit power(1Ø or 3Ø)

⑨ Consumer 51 : 67 or 51(3Ø) applicable

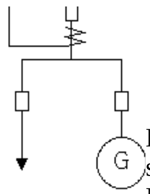


Fig. 11 Radial Common-use distribution line #2

Distributed source (wind

The standard D.C. Sequence Logic is used for interconnection line protection relaying system as Fig.12 in Korea

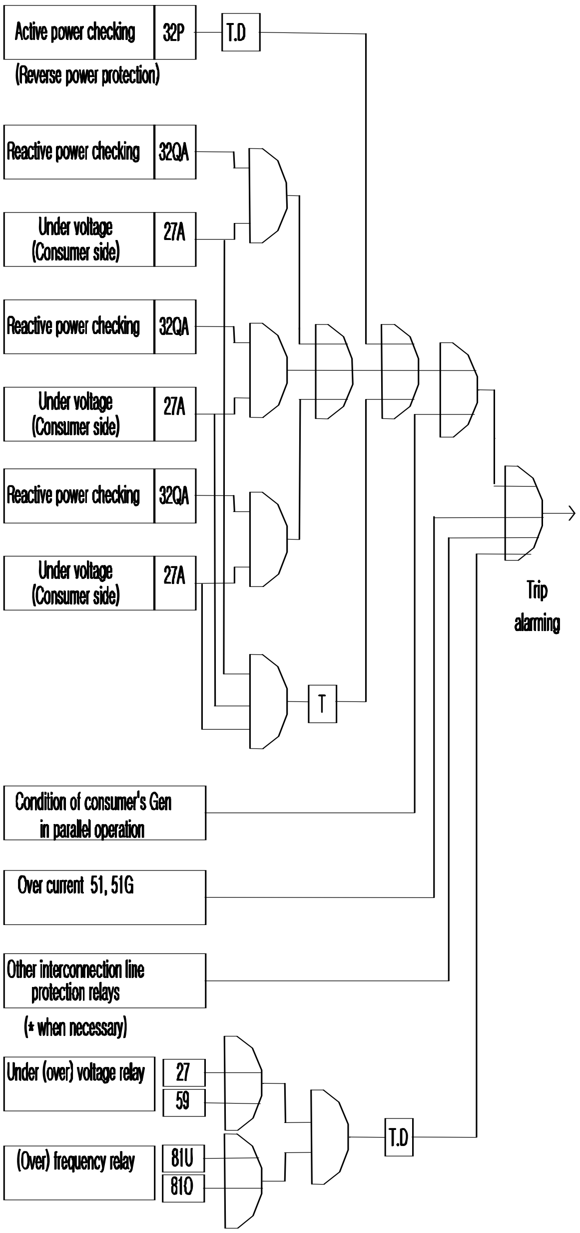


Fig. 12 Interconnection line protection relaying system D.C. Sequence Logic

If No Voltage Checking Device's installing is not available at utility S/S, then Dual Protection Relaying System is recommended at consumer side as Fig13 instead.

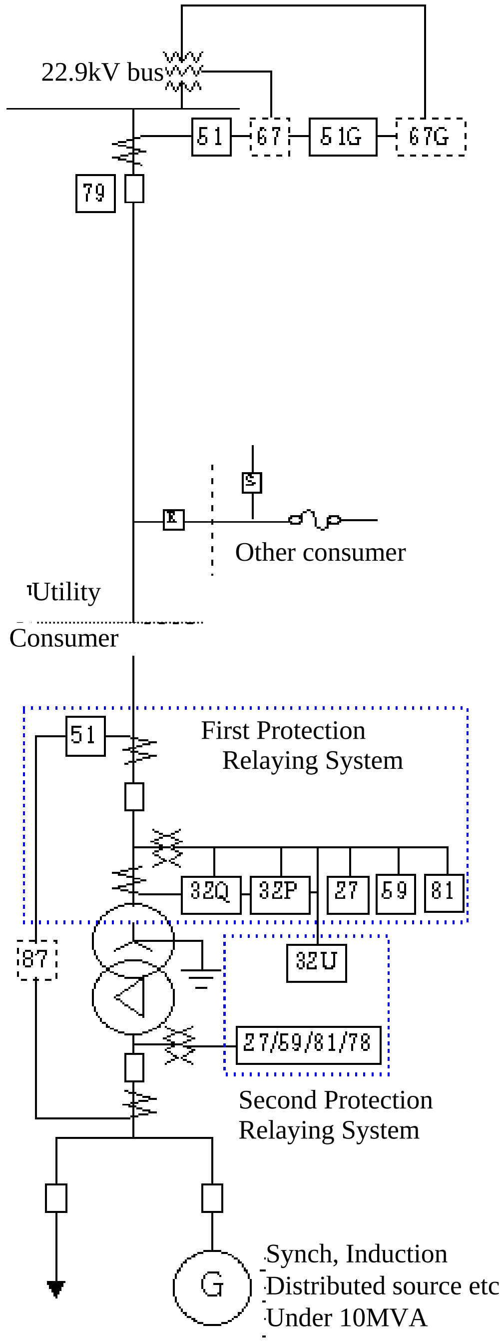


Fig. 13 Dual Protection Relaying System at consumer side[5]
(Instead of No voltage Checking device at Utility side)

① R : Recloser shall not be activated due to Co-Gen's starting current and reclosing time be over than lapse time of Co-Gen's residual voltage

② 32U : applicable to the second part of 'Dual Protection Relaying System' (Under Power Relay).

③ 59, 81 and 27/59/81/78 : relays

VI. Special points of Technical Considerations during Small Scale Co-Gen Interconnection Setup

A. Under voltage Relay(UVR;27) at Utility substation

- Necessary to escape reclosing and asynchronous operating
- Then, in case of additional PT installation impossible,
  Problem that the feeder for Consumer of Co-Gen be moved to other D/L with PT device arise
- Alternative
  .Method I –LPS(Line Potential Signalizer) install
  .Method II –Dual Protection Relaying System at consumer side

B. Reclosing relay(79) at Utility substation

- Time setting should be re-adjusted in coordination with the decoupling relays at the SSCo-Gen side of Consumer against asynchronization.

C. Decoupling Relays at Consumer's side

- If there is the blackout or instantaneous interruption due to certain reasons, Co-Gen should be decoupled in high speed before reclosing relay in Utility S/S works[4]
  .df/dt Relay
  .delta theta Relay
- Multi function Relay
  .27/59/78/81

D. Auto Load Transfer Switch(ALTS) at Consumer's side

- ALTS automatically operates and transfers to the standby power source if the blackout happen at the main power source, and returns to the main power source side after restoration of electricity, with timer setting
  -Possibility of asynchronizing
  -Operating logic and time sequence between the decoupling relays at Co-Gen and ALTS timer should be established in high reliability

E. System(Neutral) Grounding at Consumer's side

- With Co-Gen installation, Consumer should install the step-up transformer as y-y-delta, or the Grounding transformer(y-delta or zig-zag connection) to match with Utility's grounding system.

F. Reverse Active Power Relay(RPR,32P)

- Possibility of accidents due to supplying from island operation of Co-Gen during interconnected D/L line maintenance.
- Reverse flow from Consumer to Utility(in case of not permitted by the contract with Utility) to be refrained.

G. Reverse Reactive Power Relay(32Q)

- Reactive power flow in reverse from Consumer to Utility due to the short-circuit fault or ground fault at the interconnection line to be refrained.

- If the power factor of Consumer side is in lead condition, 32Q can operate wrongly. Under Voltage Relay (UVR;27) is used together for this.

VII. Conclusion

The utility-consumer interconnection provides the path for power flow between supplier(Utility) and user(Consumer) and Consumer Service Requirements and Supply Methods shall be established correctly.

Reviewing the above technical considerations, Protection Relaying System for SSC is typically established as Fig. 14.

The supply method to be selected should satisfy the consumer's load requirements and available utility supply options as well as design standards and operating and maintenance practices shall also be considered. Protection and control schemes applied to interconnection shall allow for all acceptable modes of operation and be able to detect on the utility system and in the interface substation and insure that the consumer is promptly disconnected from a faulted circuit. Special points of technical considerations such as Under Voltage Relay(UVR;27), LPS(Line Potential Signalizer), and Reclosing relay(79) at Utility substation as well as Dual Protection Relaying System, Decoupling Relays, Auto Load Transfer Switch(ALTS), System (Neutral) Grounding, Reverse Active Power Relay(RPR,32P), and Reverse Reactive Power Relay(32Q) at Consumer's side during Small Scale Co-Gen Interconnection Setup were reviewed.

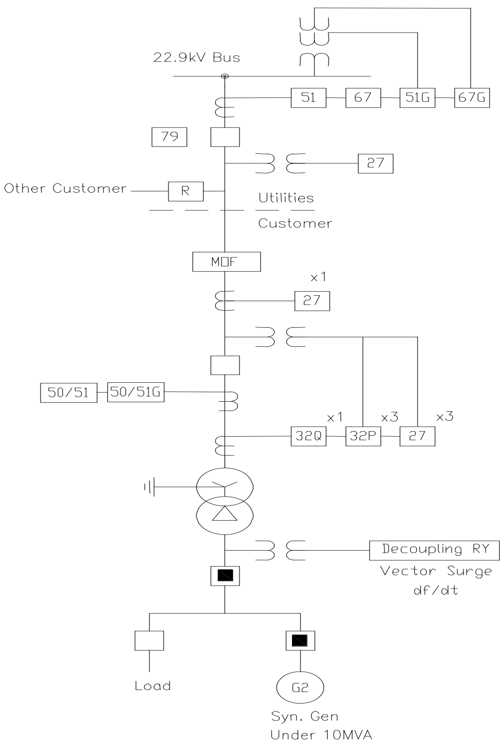


Fig. 14 Typical Protection Relaying System for Small Scale Cogeneration in Korea[5]

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IX. BIOGRAPHIES

Kap-Koo Yoon was born in 1943. He obtained his B.S. degree from Myongji University in 1967, M.S. degree from Hanyang University in 1986 and Advanced Program in Policy Studies, Korea University Graduate School of Policy Studies in 1998. He has been a Professional Engineer of Electrical Engineering since 1979. He had worked for 20 years at the Korea Electric Power Corporation (KEPCO) as a Project Manager of SCADA/EMS, and held various key positions. Now he is the President of ACE Engineering, Inc. He is also a Professor of Myongji University and Korea Energy Management Corporation, etc. and a Member of IEEE and Steering Committee for Korea Energy Economics Institute (KEEI). also a Adviser for Ministry of Science & Technology (MOST), Ministry of Construction & Transportation (MOCT), Ministry of National of Defense (MND) and Seoul Metropolitan Government. Director of The Korean Professional Engineers Association (KPEA), Korea Electrical Engineers Association (KEEA), Northeast Asia Peace Movement (NAPM), Korea Reconciliation Committee of Korean Conference on Religion & Peace (KCRP). His special field of Power System Control and Protection.

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