A Special Protection Scheme Against a Local Low-Voltage Problem and Zone 3 Protection in the KEPCO System

Ki-Seob Yun*, Byongjun Lee and Hwachang Song†**

Abstract – This paper presents a special protection scheme, which was established in the KEPCO (Korea Electric Power Corporation) system, against a critically low voltage profile in a part of the system after a double-circuit tower outage. Without establishing the scheme, the outage triggers the operation of a zone 3 relay and trips the component. This sequence of events possibly leads to a blackout of the local system. The scheme consists of an inter-substation communication network using PITR (Protective Integrated Transmitter and Receiver) for acquisition of the substations' data, and under-voltage load shedding devices. This paper describes the procedure for determining the load shedding in the scheme and the experiences of the implementation.

Keywords: KEPCO system, Local blackout, Low-voltage problem, Special protection scheme, Zone 3 protection

1. Introduction

This paper presents the establishment of a framework against a critical level of low voltage profile in the 'Bundang' region of KEPCO (Korea Electric Power Corporation) system. The local system may experience this phenomenon after a double-circuit tower outage. The outage also may trigger an action of a zone 3 protective relay because of overloading or load encroachment by load recovery dynamics. In voltage instability, the loading impedance monitored by the zone 3 relay can enter the zone 3 boundary. This may trip the component and hence cause the additional outage [1-4]. The additional outage by zone 3 protection in the 'Bundang' region can cause a local-area blackout. To prevent this critical phenomenon, a framework is equipped to the local system, which consists of load shedding devices, simple decision making logics, and a communication network between substations using PITR (Protective Integrated Transmitter and Receiver) for the required data at each substation.

The framework is in the category of special protection schemes (SPS) [5]. SPS highlights coordination of control and protection perspective to network integrity rather than component protection. Since the specific problem of the study system determines the type and purpose of the scheme, there are various types of SPS. The objective of the SPS in the paper is to improve the regional system's voltage profile after a specific outage and to prevent the additional tripping action by zone 3 relay operation.

The approach of this paper includes the control strategy of load shedding at the selected substation by means of detection of a critical outage and measurement of bus voltage magnitudes. To apply the control strategy to the system, a scheme of UVLS (under-voltage load shedding) [6-8] is necessary because the possible zone 3 operation requires rapid control after the outage. The UVLS scheme considers both characteristics of bus voltages and zone 3 relays in the local system. An SPS-UVLS system has been set up to the 154kV local structure of the KEPCO system, and a case study on the relation between load shedding and zone 3 relay was done for establishment of the scheme. This paper first describes the low-voltage problem and the additional component protection, and then depicts the procedure of determining the load shedding in the scheme against them and the experiences pertaining to implementation of the scheme.

2. Local voltage problem and blackout by zone 3 protection

This section describes the low-voltage problem of the local system after a severe contingency and related zone 3 protection causing the local blackout. Fig. 1 shows the configuration of the study region, the 'Bundang' region. This study uses the '04 KEPCO system, and the load demand of the region is 895.7 MW. It is supplied by four

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feeders and one combined-cycle generator, but the local system is separated from the feeder to bus 1 (Sunghyun).

The contingency of interest is the double-circuit-tower outage between bus 1 (Sunghyun) and 4 (Bundang). When it occurs, the regional system experiences a critically low-voltage profile and there are two overloaded routes as presented in Table 1. In the context of operational security, a certain remedial action for correcting the critically low voltage profiles should be established to protect the spreading effect of the outage. Of the two overloaded lines, also, the distance relay at the sending end of 'Yicho T/L (3-7)' is in the condition of zone 3 tripping, unless any control scheme is equipped, as shown in Fig. 2. If the zone 3 protection operates, then three substations, 'Sunghyun', 'Yatop', and 'Chowol', may experience blackout conditions.

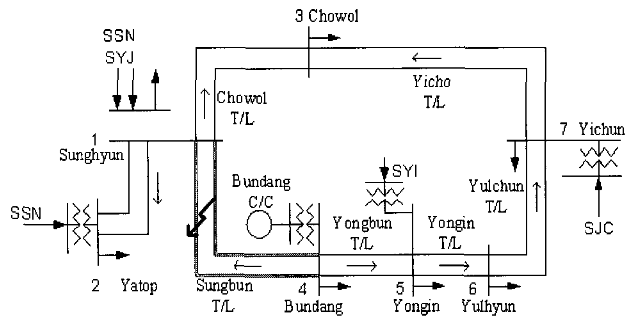

Fig. 1. Configuration of the local system, 'Bundang' region

Table 1. Overloaded lines and buses with low voltage profile after applying the outage of 'Sungbun' T/L

Outage	Overloaded lines (% overload)	Low voltage buses (Voltage [pu])
SungbunT/L	Yicho T/L (3-7) #1, #2 (219%)	Sunghyun (0.6482)
		Yatop (0.6417)
	Yulchun T/L (6-7) #1, #2 (215%)	Chowol (0.6738)
		Yichun (0.7719)

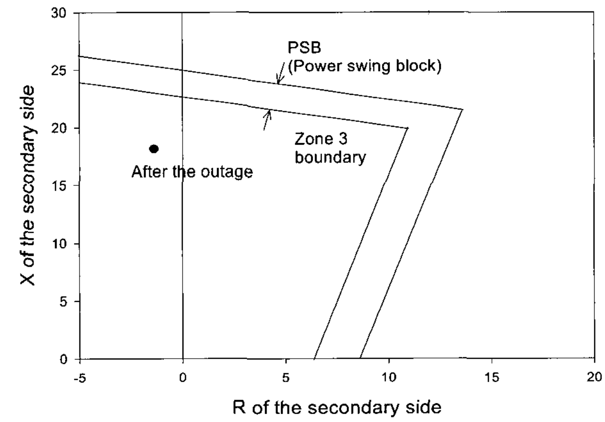

Fig. 2. Loading Z at the sending end of 'Yicho T/L' after the outage

To prevent the low voltage problem, a UVLS scheme was planned to be installed as a special protection scheme based on detection of the double-circuit-tower outage. UVLS is usually one of the response-based special protection schemes (SPS) activated by voltage profile, and control action delay is typically between the range of 1~5 seconds for coordination with system load characteristics. However, the UVLS applied in this paper is triggered by the double-circuit-tower outage – this is an event-based SPS, and immediate control action is required for prevention of the possible blackout resulting from the additional component trip by zone 3 protection.

3. Load shedding strategy of SPS-UVLS scheme

This section reports the study procedure and results for the load shedding strategy of the implemented SPS-UVLS.

3.1 Study procedure

The study is based on the following conditions:

- Peak data of '04 KEPCO system;
- Overloaded lines with more than 150% loading are checked when N-1 and N-2 contingencies are applied;
- Zone 3 relay impedance locus in local systems are examined, and zone 3 relay is set not to operate when the monitored component's current is over 150% of the current rating;
- Allowable overloading delays of 154kV and 345kV transmission lines are 20 minutes under 100~120% continuous current and 5 minutes under 120~150% continuous current;
- The minimum bus voltage from KPX (Korea Power eXchange) recommendation is 0.95 [pu].

The study conditions above mainly affect the control location and amount of UVLS schemes. Fig. 3 shows the flowchart of the procedure for load shedding in this study. Assuming that a set of contingencies is given, the procedure applies a contingency from the set and determines whether the contingency needs UVLS. If the present contingency is severe, the procedure performs the locations and amount of load shedding. For this purpose, the procedure performs power flow calculation and checks voltage profile, line flows, and loading impedances monitored by zone 3 relays. It determines the load shedding locations and amount in an iterative way until no voltage is less than V_{min}, no line flow is greater than $1.2F_{min}$, and the line rating and no zone 3 relay causes an additional trip followed by a local blackout. Control locations are chosen depending on which bus has the lowest voltage magnitude, which buses are supplied through the overloaded lines. Then, loads at the selected locations are shed with the designated amount of load shedding, ΔMW, until the system satisfies the criteria of voltage and line flows (V_{min} and $1.2F_{min}$). Next, the loading impedances of the relays in the study local system are located in R-X plane with the zone 3 boundaries to examine whether all the relays have sufficient relay margins [4, 9], which measure the distance of a loading impedance from the zone 3 boundary. If not, it executes more load shedding; otherwise, it analyzes another contingency.

3.2 Load shedding strategy for 'Sungbun T/L' outage

As explained in Section 2, when 'Sungbun T/L' is tripped, the voltage profile in the 'Bundang' region is critically low, and overloading of 'Yicho T/L' and 'Yulchun T/L' is beyond around 60% of the emergency rated currents. Also, the additional trip by a zone 3 protection relay may occur and lead the local blackout. In contingency analysis, only 'Sungbun T/L' outage critically deteriorates the security of the region, so an event-based UVLS scheme can be devised.

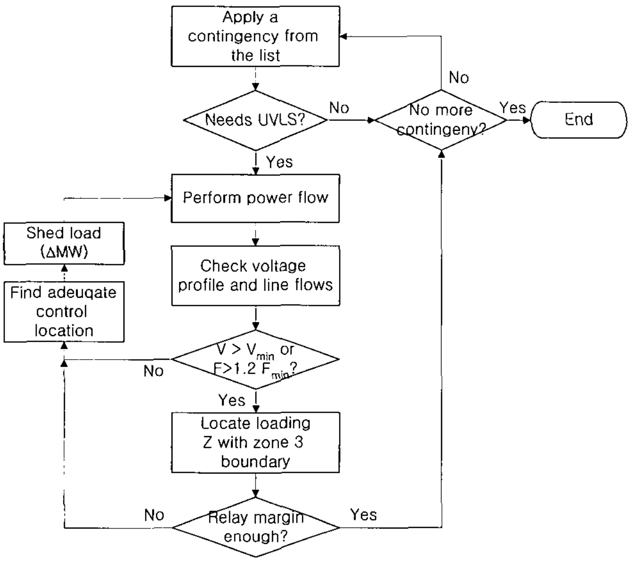

Fig. 3. Flowchart for load shedding location and amount

Using the procedure in Fig. 3, adequate load shedding locations and the total amount are decided. The control amount that satisfies the voltage minimum (0.95 [pu]) and the overload maximum (120%) is about 86.3 MW, and after the consideration of a 10%-margin, the applied control amount is 95.3 MW. The most effective control location is 'Yatop S/S', but the maximum load amount at this substation is 79.4 MW – this is to prevent the blackout of the entire station, and hence 'Sunghyun S/S' shares the remaining amount of 15.9 MW for load shedding.

To verify whether the control is appropriate for restoring security of the region after 'Sungbun T/L' outage, power flow solution is traced while the direction of the load shedding is done, investigating voltage, thermal limits and relay margins of severely loaded lines. Table 2 shows voltages and current injections of 'Yatop S/S' and 'Sunghyun S/S' obtained from the power flow tracing to the load shedding direction. From Table 2, one can see that the decided amount of load shedding improves voltages at those buses and satisfies the voltage criterion. Fig. 4 presents P-V curves of the two substations with respect to the load shedding.

Table 3 describes real and reactive power flows at the sending ends of 'Yicho T/L' and 'Yulchun T/L' and their loading impedances by the power flow tracing. Fig. 5 and Fig. 6 illustrate the locus of loading impedances with respect to the load shedding at 'Yicho T/L' and 'Yulchun T/L' respectively. These two routes experienced severe overloading after the outage. When the decided amount of load shedding is applied, the line loadings are below 120%. In addition, the relay margins of those lines are 35.68 [Ω] and 35.75 [Ω], so these relay margins are enough to restrain undesired protective operation of these zone 3 relays that may lead to a blackout.

Table 2. Voltages and current injections of the selected locations w.r.t. load shedding

P_{SHED} [MW]	Yatop S/S				Sunghyun S/S			
	Volt [pu]	Angle [°]	IR [A]	IX [A]	Volt [pu]	Angle [°]	IR [A]	IX [A]
0	0.6417	-68.29	1530.8	1152.2	0.6482	-67.25	300.78	227.04
8.5	0.7667	-61.18	1240.7	933.78	0.7716	-60.46	244.06	183.38
21.5	0.8194	-57.95	1102.8	829.80	0.8235	-57.34	216.89	163.24
33.7	0.8533	-55.78	1006.2	757.04	0.8569	-55.24	198.11	149.44
45.3	0.8797	-54.02	927.1	697.30	0.8829	-53.53	182.77	137.83
56.3	0.9014	-52.54	859.7	646.72	0.9042	-52.09	169.65	127.54
66.9	0.9199	-51.25	800.2	602.99	0.9224	-50.84	157.68	118.89
76.8	0.9359	-50.11	747.2	562.42	0.9382	-49.72	147.49	110.85
86.3	0.9502	-49.07	699.2	526.38	0.9523	-48.71	137.88	104.01
95.3	0.9630	-48.13	655.5	492.97	0.9648	-47.79	129.21	97.53

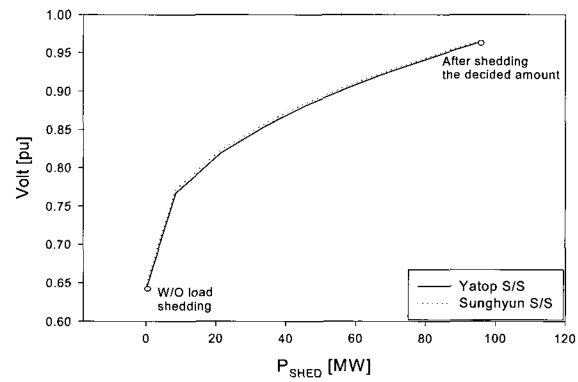

Fig. 4. P_{SHED}-V curves of 'Yatop S/S' and 'Sunghyun S/S' w.r.t. load shedding

Table 3. Line flow and the secondary side reactance w.r.t. load shedding

P_{SHED} [MW]	Yicho T/L				Yulchun T/L			
	P_{flow} [MW]	Q_{flow} [MVAr]	2nd R [Ω]	2nd X [Ω]	P_{flow} [MW]	Q_{flow} [MVAr]	2nd R [Ω]	2nd X [Ω]
0	223.2	148.2	-1.3898	18.1549	269.5	169.6	-0.7689	15.4846
8.5	219.8	98.0	4.07119	26.0232	264.8	119.3	3.26116	21.5410
21.5	212.6	74.6	8.81298	30.0910	257.8	95.9	6.54124	24.6280
33.7	206.2	58.9	13.2287	32.7027	251.4	80.2	9.47938	26.7025
45.3	200.1	46.3	17.6655	34.5492	245.3	67.6	12.3652	28.3003
56.3	194.4	35.8	22.0835	35.7425	239.6	57.0	15.2267	29.5163
66.9	189.1	26.7	26.4594	36.3541	234.2	47.9	18.0367	30.4296
76.8	184.0	18.6	30.7889	36.4576	229.1	39.9	20.8026	31.0784
86.3	179.1	11.4	35.0086	36.1076	224.3	32.7	23.5466	31.4776
95.3	174.5	4.90	39.0493	35.3233	219.7	26.1	26.2580	31.6545

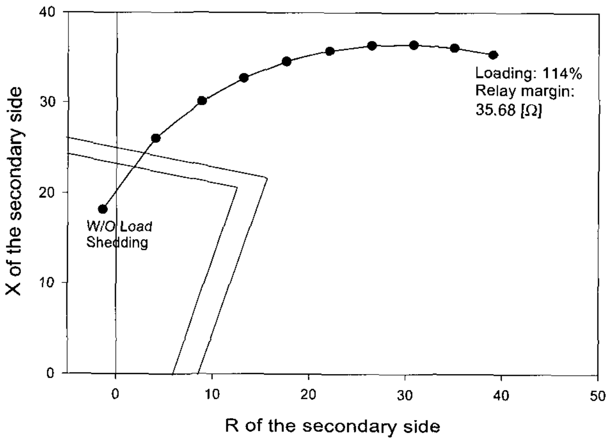

Fig. 5. Locus of loading Z at the sending end of 'Yicho T/L' w.r.t. load shedding

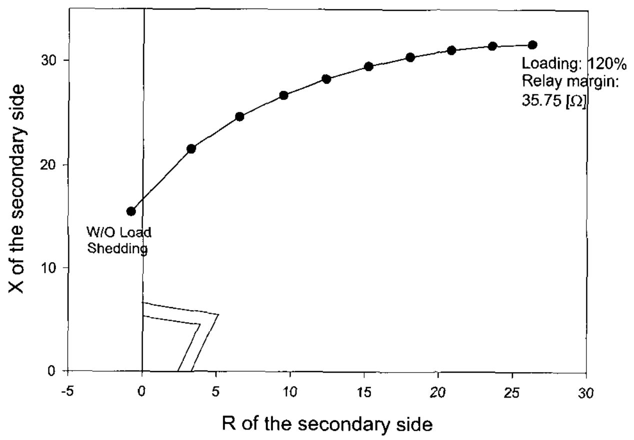

Fig. 6. Locus of loading Z at the sending end of 'Yulchun T/L' w.r.t. load shedding

4. Implementation of the SPS-UVLS

This section presents the SPS-UVLS structure and the experiences of its implementation on the local system. Fig. 7 describes the structure of the UVLS scheme. When the system detects the operation of the circuit breaker (CB) at the 'Sunghyun S/S' side of 'Sungbun T/L', the scheme employs a simple logic block that activates load shedding. The conditions for condition action are the outage of 'Sungbun T/L' and the voltages of 'Sunghyun S/S' and 'Yatop S/S' being below 0.95 [pu]. If the block decides load shedding, then the command is transmitted to load shedding relays at the two load shedding substations via PITR (Protective integrated transmitter & receiver) and an optical fiber. The CB signal can also be transferred to 'Yatop S/S' through the communication channel. To realize the scheme, two UVLS systems with UVR (27) relays are equipped at the two substations. In load shedding cases, the scheme trips 5 distribution lines under 'Sunghyun S/S' and 10 lines under 'Yatop S/S'.

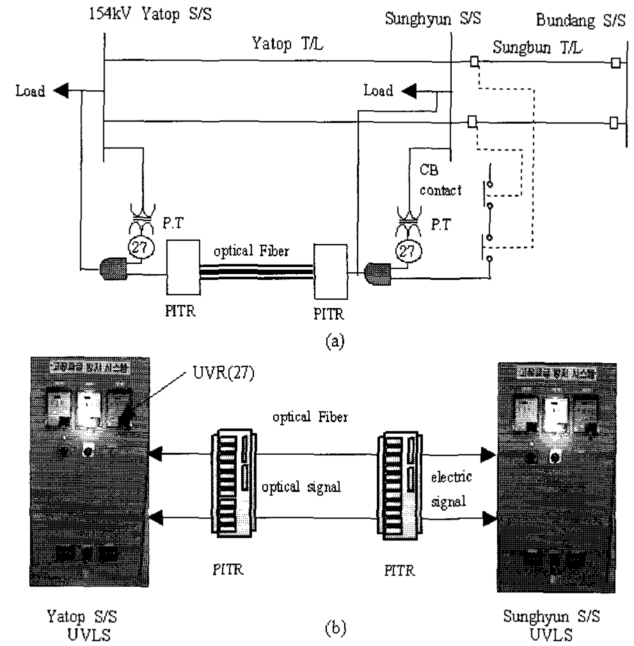

Fig. 7. Structure of the implemented SPS-UVLS

In the experiences of operation, even when the circuit breakers at the 'Bundang S/S' side of 'Sungbun T/L' are re-closed, the ones at the 'Sunghyun S/S' side of the lines are not re-closed because of the voltage (magnitudes and angles) difference between the bus and lines. In this case, line voltage magnitude and angle at the 'Bundang S/S' side of 'Sungbun T/L' are 1.0157 [pu] and -30.83 [degree], while those at 'Sunghyun S/S' are 0.6482 [pu] and -67.25 [degree]. This condition of low bus voltage, large magnitude and angle deviations stop the re-closing relays from being energized according to the re-closing rules of Table 4. To solve this difficulty of re-closing, the re-closing relay setting for 'Sungbun T/L' is altered to include the synchronization checking logic with the additional input UVR condition. The logic is shown in Fig. 8. The re-closing setting of the under-voltage relays in

UVLS is done using the signal from re-closing relay such that if the following conditions:

- 27HB, 27HL (Bus live, Line live): 80% of the rated voltage at the sending end, and
- 27LB, 27LL (Bus dead, Line dead): 30% of the rated voltage at the receiving end, are met, the under-voltage relays try to re-close in conjunction with the circuits' re-closing.

Table 4. Relay re-closing rules for 154 and 345kV lines

Voltage	Bus voltage [%]	Voltage difference [%]	Angle difference [°]
154kV	80% of rated voltage	△V : within 10%	±25°
345kV			±30°

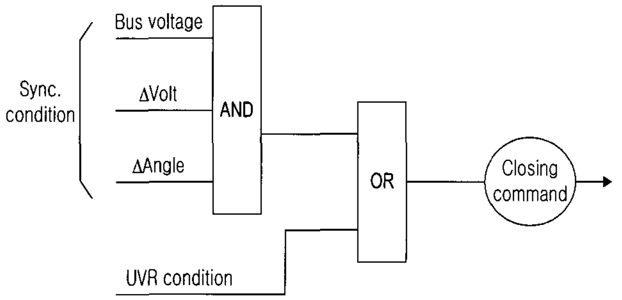

Fig. 8. Synchronization and UVR condition checking logic

5. Conclusions

This paper presents an SPS-UVLS scheme established in the 'Bundang' region in the KEPCO system against a critically low voltage profile and a local blackout resulting from the additional trip of 'Yicho T/L' by zone 3 protection after 'Sungbun T/L' double-circuit tower outage. Since the time delay of zone 3 relay operation is 100 cycles, immediate control action after the outage is required for prevention of the local blackout. The applied scheme is an event-based SPS that is activated by the detection of the severe outage and voltage profile at the locations of load shedding. The SPS-UVLS is composed of load shedding devices, decision making logics, and a communication network. In addition, the logic for checking synchronization and under-voltage relays' condition is added for re-closing setting in the UVLS devices.

Acknowledgement

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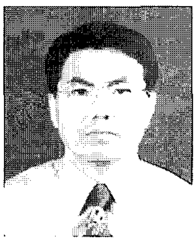

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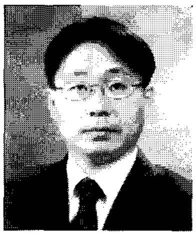

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