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Analysis of Power Restoration Process Using Battery Energy Storage System

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Abstract

So far many papers have been reported on various application in addition to the existing BESS(Battery Energy Storage System) equipment that stabilizing the output of the renewable energy and adjusting the frequency of the power system. In 2013, the US EPRI has reported a study of the primary power plant starting using BESS for the replacement of two black start generators of American Electric Power(AEP) that will be demolished. As the social interest in the power outage has increased since wide-area blackout in South Korea in 2011 it is time to research shortening power restoration time as well as reliability of the power restoration plan. In case of wide area black-out, the primary transmission line should be energized at first after opening all circuit breaker in power system. Since these transmission lines are long-distance and no-load, various problems may occur in the process of energizing. In this paper, the restoration process using BESS for primary transmission line was analyzed. PSCAD / EMTDC was used for simulation.

Keywords: Blackout, BESS, Restoration, PSCAD/EMTDC

INTRODUCTION

Recently many papers have been reported on various application, in addition to the existing BESS(Battery Energy Storage System) equipment that stabilizing the output of the renewable energy and adjusting the frequency of the power system[1-6]. In 2013, the US EPRI has reported a study of the primary power plant starting using BESS for the replacement of two black start generators of American Electric Power(AEP) that will be demolished[7]. Siemens also supplied BESS with a capacity of 2.85[MW] / 720[KWh] for the Black Start of the German gas turbine power plant. However the report was not published. Since BESS can operate at high speeds and there is no limit on the installation site, it is expected that if it can replace the self-starting generator, it can reduce the current transmission line which is composed of long distance. In addition, it is expected that it will be possible to shorten the restoration time. Currently, the Korean power system is operating near the stability limit due to the continuous load increase, so that the possibility of large scale power outage is increasing. In 2011, a blackout occurred in each region in Korea to prevent the frequency drop due to reserve power lack. After this in Korea, as the social interest in the power outage has increased since wide-area blackout. Therefore it is time to research shortening the power restoration time as well as reliability of the power restoration plan.

In the case of a total blackout or wide-area blackout, other countries' initial countermeasure have adopted method of entire power system restoration which sequentially restores outage area by opening entire power system and energizing prime power supply system. Korea adopts the same method. However, this method can cause various problems such as the Ferranti effect [8], since the long-distance no-load transmission line is energized in restoration process. In this paper, the restoration process using BESS for primary transmission line was analyzed. PSCAD / EMTDC was used for simulation.

CASE STUDY

The Korean primary transmission systems is divided into seven regions. Yeongnam area primary transmission line and Jeju area primary transmission lines were examined in this paper.

Figure 1 shows the primary transmission lines in Yeongnam region and Figure 2 shows the primary transmission lines in Jeju.

The self-starting generator in the primary transmission lines of Yeongnam area is designated as the Cheongsong pumped storaged power plant and the primary supply power plant is the Ulsan Combined Cycle Power Plant#1. The self-starting generator in Jeju primary transmission line is Jeju GT(Gas turbine)#3 and the primary power plant is Hanlim Combined Cycle Power Plant#1.

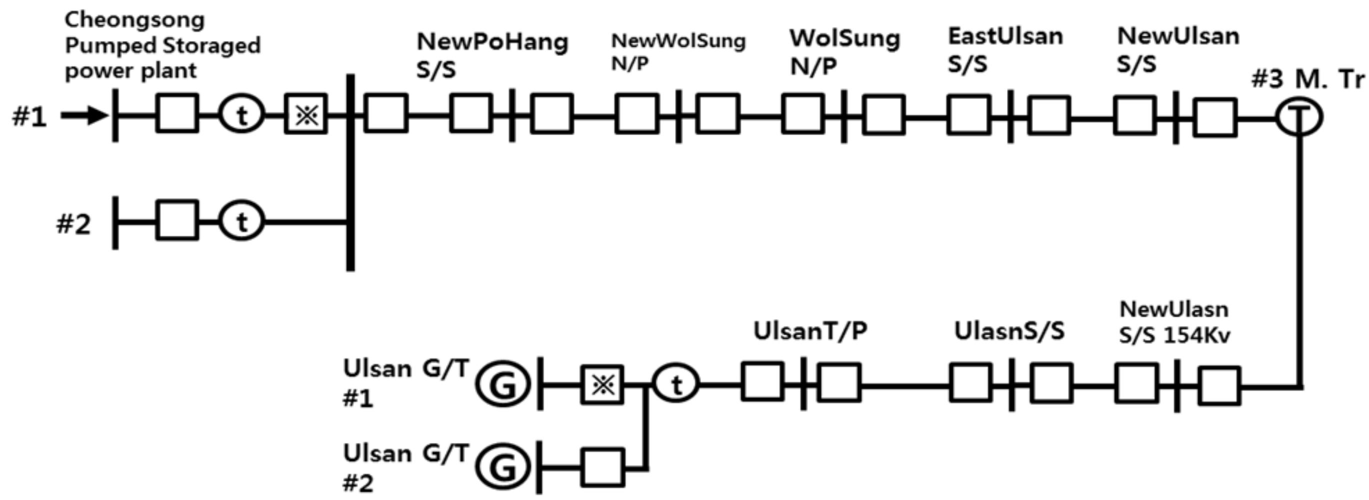


Figure 1: Yeongnam primary transmission line

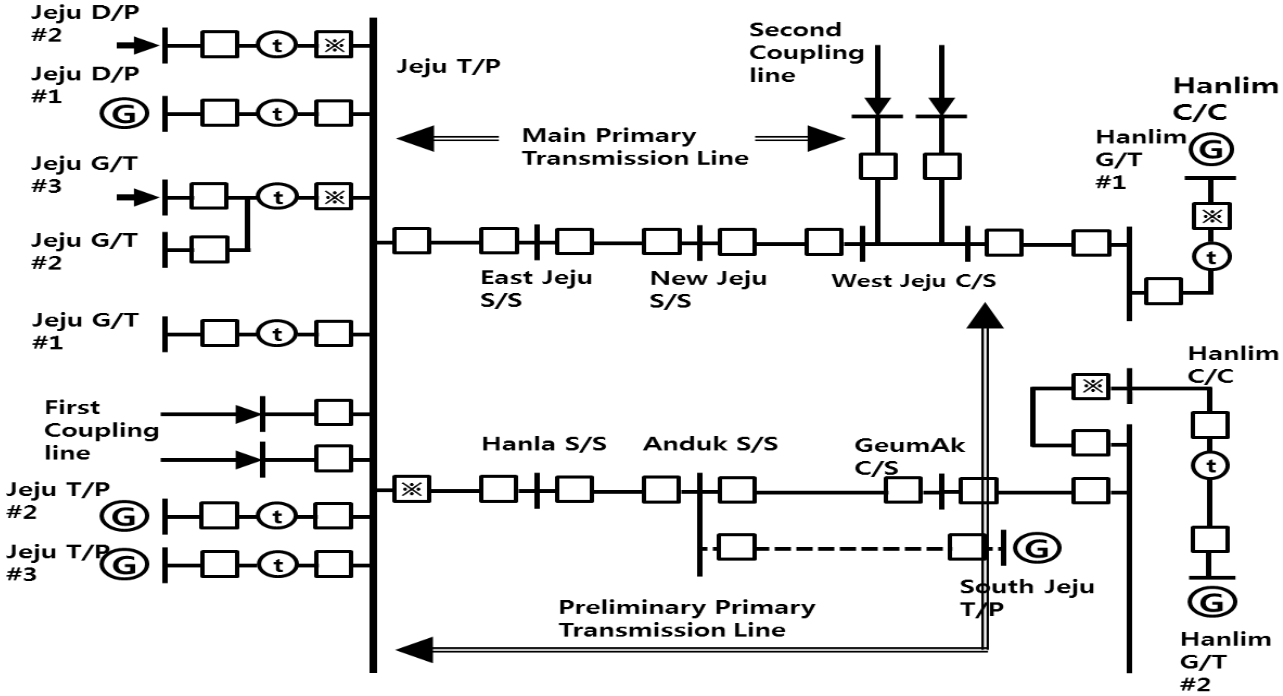


Figure 2: Jeju primary transmission line

Ulsan Combined Cycle Power Plant#1 Start process

As described above, after opening the entire system, for Supplying power to Yeongnam area, the primary transmission line shown in Figure 1 is energized and finally Ulsan Combined Cycle Power Plant is restored.

The Ulsan Combined Cycle Power Plant receives the power from the self-starting generator through the primary transmission line, and then prepares to start the motor load for the GT#1 start. At this time, GT#1 is first activated and GT#2 and ST#1 are activated using the power output from the GT#1. Figure 4 shows the GT#1 start-up procedure in terms of motor load.

Hanlim Combined Cycle Power Plant#1 Start Process

Hanlim Combined Cycle Power Plant#1 is composed of two gas turbines (GT#1, GT#2) and one steam turbine (ST#1) like the Ulsan Combined Cycle Power Plant#1. And the power plant restoration procedure of Hanlim Combined Cycle Power Plant#1 power plant is the same as Ulsan Combined Cycle Power Plant#1 in case of total blackout. However, the starting motor at the Hanlim Combined Cycle Power Plant#1 is different in that it starts using its own diesel generator.

Restoration procedure Simulation

Ulsan Combined Cycle Power Plant#1 Start process Simulation

Looking at the Yeongnam area primary transmission line in Figure 1, it consists of a long distance line(About 205.665km) from the self-starting generator, Cheongsong pumped storaged power plant to the Ulsan Combined Cycle Power Plant.

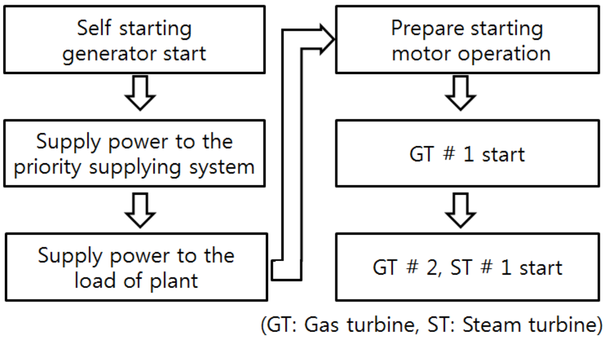


Figure 2: Primary power supply plant restoration process diagram

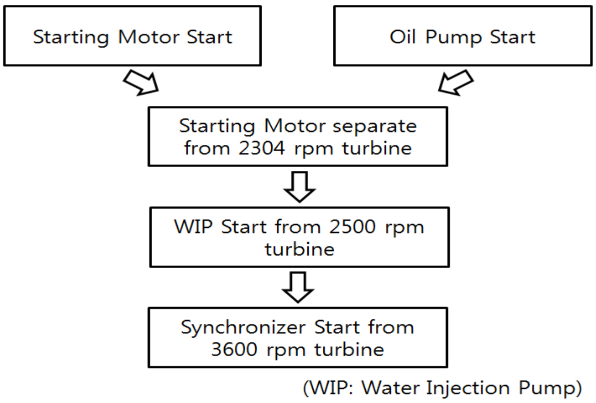


Figure 3: Generator start-up process

When long distance transmission line is energized, various problems such as ferranti may occur. To prevent this problem, it is necessary to shorten the primary transmission. This can be expected to shorten the restoration time. Therefore, in this paper, simulation is performed considering BESS installation location as follows.

1) Ulsan T / P substation

The load configuration for simulating the restoration procedure of Ulsan Combined Cycle Power Plant#1 is shown in Table 1 below. Three motors with relatively large capacity (starting motor, oil pump, water injection pump) were set as the motor load and set to 2[MVA](pf 0.95) inside the plant load. The simulation scenario is based on the generator start procedure in Figure 3. Table 2 shows the restoration procedure simulation scenario. As shown in Figure 4, the simulation system was constructed using PSCAD / EMTDC.

Table 1: Ulsan combined cycle power plant#1 load configuration

Load	Capacity
Internal load	2[MVA](pf 0.95)
Start Motor	2000[hp]
Oil Pump	75[kW]
Water injection pump	150[kW]

Table 2: Simulation scenarios

[s]	Contents
0	#1 BESS Start, #2 BESS Start
5	Ulsan Combined internal load pressure (2[MVA], pf=0.95)
7	start motor, Oil pump Start
25	Starting motor separation
26	Water injection pump start
50	Simulation Termination

When the restoration procedure including the transmission line is carried out, it can be confirmed that the voltage waveform is not stable when the load of Ulsan Combined Cycle Power Plant#1 receive the power in 5 seconds as shown in Figure 6. After a large capacity motor is energized in 7 seconds, Voltage stabilized. However, after the start motor starting, the start motor was disconnected by the start procedure, and power plant restoration failed with the voltage fluctuation.

Hanlim Combined Cycle Power Plant#1 Start Process

Figure 2 shows that the main primary transmission line in Jeju consists of long distance transmission lines(About 115.7km).

This is the same as the primary transmission lines from Jeju GT#3, which is a self-starting generator, to the Hanlim Combined Cycle Power Plant as well as Yeongnam primary transmission line. Therefore, simulations were performed considering the location of BESS as in the previous section.

1) NewJeju Substation

As described above, the Hanlim Combined Cycle Power Plant#1 starts the starter motor as its own diesel generator when the generator is started. Therefore, the motor load for simulation is simulated considering only the oil pump and the water injection pump in Table 3. Also, the internal load of plant was set to 2[MVA](pf 0.95). The following table 3 is a simulation scenario of the restoration process.

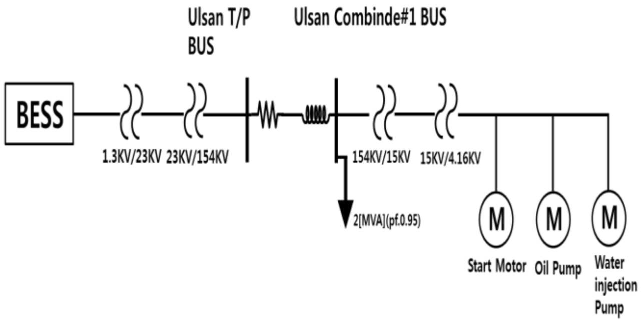


Figure 4: Simulation system one-line diagram

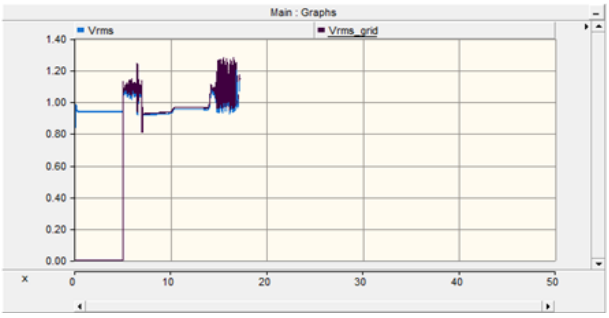


Figure 5: Voltage profile_installed Ulsan T/P substation

Table 3: Simulation scenarios

[s]	Contents
0	#1 BESS start, #2 BESS start
5	Hanlim combined#1 internal load pressure (2[MVA], pf=0.95)
7	Oil pump start
26	Water injection pump start
50	Simulation Termination

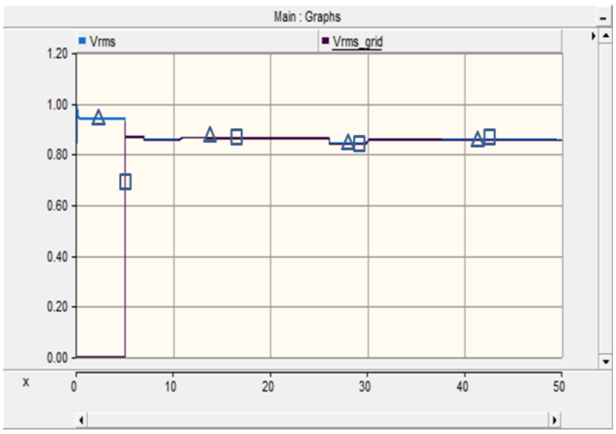


Figure 6: Voltage profile__installed NewJeju substation

(∆: PCS Voltage □: Grid voltage)

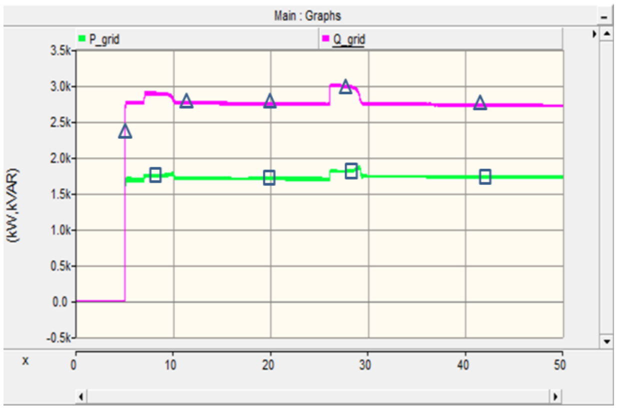


Figure 7: P,Q capacity_installed NewJeju substation

(□: Active power ∆: Reactive power)

As shown in Figure. 7, any problem was not found in Jeju area when restoration was carried out

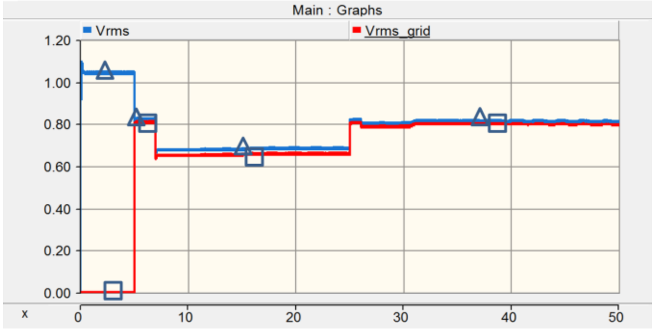
Ulsan Combined Cycle Power Plant#1 Failure Analysis

Wide-area power restoration in the countries of the world opens the whole system and presses the primary transmission line, and Korea adopts the same method.

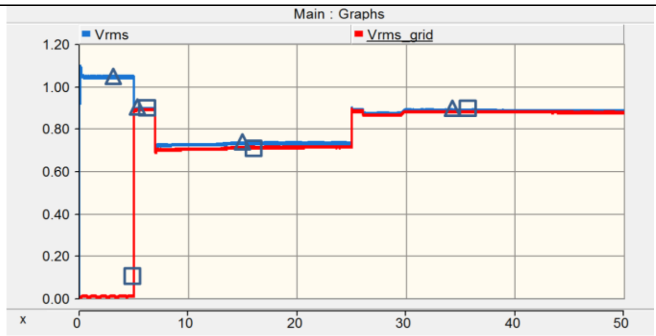
This method energizes the no-load long-distance transmission lines in the process of restoring the outage and can cause various problems.

In this paper, to analysis the cause of failing to start the Ulsan Combined Cycle Power Plant#1 power plant, Yeongnam region, effect of the line charge capacity and effect of line inpedence were analyzed.

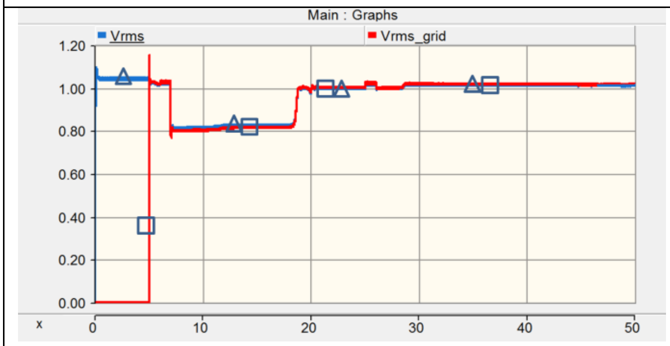
Effect of the line Charge capacity



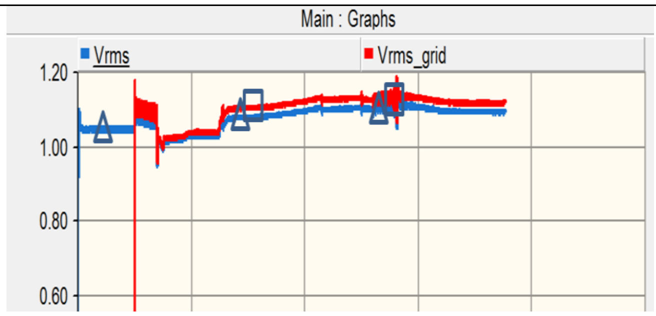
1) When B ≈ X (△: PCS Voltage □: Grid voltage)



2) When B ≈ 5X (△: PCS Voltage □: Grid voltage)



3) When B ≈ 10X (△: PCS Voltage □: Grid voltage)



4) When B 〉 11X (△: PCS Voltage □: Grid voltage)

Figure 9: Variable ratio of X and B simulation result

It was confirmed that when the Ulsan Combined Cycle Power Plant#1 power plant was started through the primary transmission line of the Yeongnam region, the operation failed. However, it can be confirmed that the power is normally started when the power supply is firstly supplied through the primary transmission line in Jeju. Therefore, the length of each line was checked to see if the problem in the simulation results was due to the charging capacity of the line length. Table 4 below shows the line data reviewed in the simulation.

Since the charging capacity is determined by the charging current (I_c=V/X_c) of the line the respective charging currents are obtained as follows.

1) Ulsan T/P ~ Ulsan Combined#1 : 6.13[pu]

2) NewJeju ~ Hanlim Combined#1 : 17.84[pu]

As can be seen from the calculation results, it can be seen that the charge capacity of Jeju area is about 3 times. Therefore, it can be confirmed that the problem occurred when the Ulsan Combined Cycle Power Plant#1 is energized is not caused by the charging capacity of the line.

Table 4: Line data

Line	[kV]	[m]	R[pu]	X[pu]	B[pu]
Ulsan T/P ~ Ulsan Combined#1	154	7221	0.000707	0.007164	0.15493
NewJeju ~ Hanlim Combined#1	154	21000	0.01215	0.05422	0.05325

Effect of Line Impedance

As shown in Table 4, the X value and the B value in the Jeju primary transmission line are approximate, and the B value in the Yeongnam area primary transmission line is about 20 times the X value. Therefore, this paper simulated various ratio of X and B in the transmission line of Yeongnam.

As shown in Figure. 9, it can be seen that unstable signal occurs when X/B ratio is B 〉 11X. Therefore, when the BESS is used to energize the primary transmission line, it is necessary to construct the supply line first considering the line impedance ratio

CONCLUSION

In this paper, the restoration process using BESS for Korean primary transmission system was simulated and analyzed using PSCAD / EMTDC. As a result of simulation, it is confirmed that transmission line X / B ratio can cause unstable signal when BESS energizes the primary transmission line. Therefore, if BESS energizes the primary transmission line, detailed analysis based on EMTP simulation is necessary. As the inverter output contains harmonic components, harmonic oscillation should be verified as well as the reactive power supplement.

The analysis results in this paper can be used as a basic study for analyzing the possibility of unstable signal due to the harmonic components included in the inverter output in the future.

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