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주요 상정사고로 인한 송전혼잡 문제에 대한 선형계획법을 이용한 부하차단 알고리즘

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Load Shedding Algorithm Using the Linear Programming for Congestion Problems by a Major Contingency

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Abstract - Due to a major contingency, the congestion of the transmission may happen in power systems. In order to manage the congestion problem, load curtailment is one of the ways to resolve the problem. It is essential that the systematic and effective mechanism for the load shedding be developed. In this paper, the load shedding algorithm using the linear programming for the congestion problems by a major contingency is proposed. The simulations of the proposed algorithm are performed for the power system of Korea and their results are presented.

1. INTRODUCTION

Most of the electric power in the power system of South Korea is flowing from the south area to the north area, Seoul, in the capital of South Korea. Electrical loads over about 40% of the total loads are mostly concentrated in the capital area and generation plants are mainly located in the south area of South Korea. Due to the characteristic, transmission congestion is one of important research issues. Because of the limits of the power flows from the south to the north which are anticipated to be increased more and more in the future, these congestion situations may cause a serious voltage stability problem in emergency of the power system. In the transmission system plan, it is basically considered to secure the power systems for electric power demands, various operating points of generation outputs, contingencies and so on. Transmission systems must also stay within the limits in the event of unplanned outages of transmission lines or transformers[1][2]. Sufficient transmission capacities are needed to meet the operation condition within the limits in the event of unplanned but constraints such as cost problems or environment problems are followed. Moreover, the transmission capacities have boundaries due to the thermal capacity limits, disturbances, and etc.. When the suppliers and consumers of electric energy desire to produce and consume in amounts that would cause the transmission system to operate at or beyond one or more transfer limits, the system is said to be congested[1]. Modern power systems are required to maintain the high reliability and good power quality. Transmission congestions may bring about problems such as voltage instability and frequency instability in the power systems. Therefore, the transmission congestion management is also a main issue in the country which has power markets[3][4]. There are some methods to mitigate the power system congestion which include ways such as improvements of power systems characteristics, replacement of transmission network, constrained operation of generators in a management point of view. In order to solve transmission congestions, a method of the redistribution of generator outputs using the line sensitivity was proposed[5]. Nevertheless, the system situation which can not operate the power systems normally without load shedding may occur. Specific contingency faults are unable to meet the limits in power systems. Therefore, the load shedding algorithm using the linear programming in emergency is presented in this paper. The purpose of the proposed algorithm is to provide the solution of the transmission congestion in emergency for major failures in the power system. In order to show the effectiveness of the proposed algorithm, it has been tested on the power system of KEPCO(Korea Electric Power Corporation).

2. LOAD SHEDDING ALGORITHM

In this paper, the load shedding algorithm using the linear programming in emergency can calculate the minimum amounts of interruptible loads. The proposed method minimizing the total amounts of interruptible loads as follows:

$$Min \quad \sum \Delta P_{Di} \tag{1}$$

subject to:

$$\sum \Delta P_i = 0$$

$$[S]\Delta P_i \le \Delta LF$$

$$-[B]\Delta\theta = \Delta P_i$$

$$\Delta P_{Gi}{}^{min} \le \Delta P_{Gi} \le \Delta P_{Gi}{}^{min}$$

$$0 \le \Delta P_{Di} \le \Delta P_{Di}{}^{max}$$

Where ΔP_{Di} : amounts of interruptible load at bus i

Where $i \in I_D$, I_D is a set of load bus

ΔP_i : $\Delta P_i = \Delta P_{Gi} - \Delta P_{Di}$

$[S]$: line sensitivity matrix in which the elements of the matrix are Congestion distribution Factors(CDF)[2]

ΔLF : exceeded amounts of real power line flow limits

$[B]$: susceptance matrix of Y_{bus}

ΔP_{Gi}: variation values of generation output at bus i

Where $i \in I_G$, I_G is a set of generator bus

The solution of the optimization problem eq.(1) can be obtained using linear programming(LP) or nonlinear programming. The solution gives an optimal generation at the generation buses and loads at the load buses. The new obtained operating points do not violate the line capacities and satisfy the power equation at all buses. When a fault occurs in power systems, the proposed algorithm is basically applied. The flowchart of the proposed algorithm is described in Fig 1.

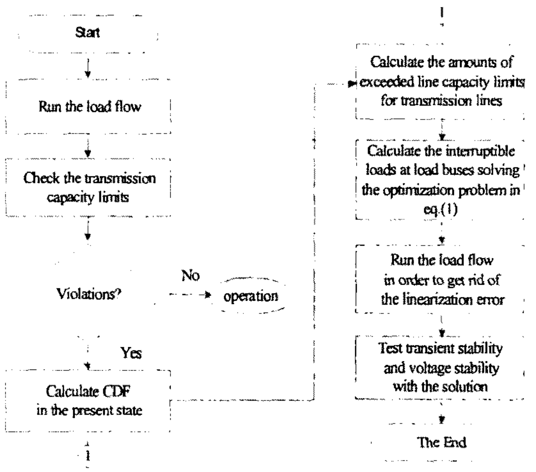

Fig 1. The flowchart of the proposed algorithm

If the program starts, the program runs the load flow firstly. Transmission line capacity limits are checked for the interested transmission lines. If all transmission lines do not violate the limits, the present state is maintained. Otherwise, it calculates CDF for the power system with the outage. Next, it calculates the amounts of exceeded line capacity limits for transmission lines. In order to get rid of the violation of the transmission capacity, it determines the interruptible loads at load buses solving the optimization problem in eq.(1). The linearization errors are reduced by running the load flow. Finally, it checks transient stability and voltage stability with the solution. If the power system is stable with the solution, the corresponding control scheme must be applied.

3. Case Study

In order to investigate the proposed algorithm, it has been also tested on real power system of KEPCO in this paper. The data of the real power system is the system data for the estimated peak demands in the summer of 2005. The test data is summarized in Table 1.

Table 1. The system data for the estimated peak demands in the summer of 2005

Index	Contents	Remark
Total capacities of the generation	61255 MW	
Total loads	53168.2 MW	
Capital Area loads	21708.3 MW	
Total capacities contracted in Direct Load Control Program	2098 MW	
Capital Area capacities contracted in Direct Load Control Program	367 MW	
Number of the transmission line	1,295	
Number of the bus	765	5
	345	103
	154	664

In the test data, the Capital Area loads include the loads of Seoul, West Seoul, Suwon and Incheon Area in the load flow data of PSSE. The ratio of the Capital Area loads for the total load is about 40.8%. Most of the electric power in the power system of Korea is flowing from the south area to the north area, Seoul, in the capital of Korea because generation plants are mainly located in the south area of Korea and many loads are concentrated in Capital Area. Accordingly, it is necessary that the electric power flowing from the south area to the Capital Area should be investigated for several major contingencies. The real power flowing in the interested transmission lines is presented in Table 2 and 3.

Table 2. Real power flowing between the Jungbu Area and Capital Area

Bus	Volt.	Bus	Volt.	From MW	From Mvar	From MVA	Lim MVA
Hwaseong 3	345	Asan 3D	345	1200.3	199.1	1216.7	2191.8
Hwaseong 3D	345	Asan 3	345	-1257.6	223.4	1277.3	2191.8
New Anseong 7	765	New Seosan 7	765	-1354.3	-116.1	1359.3	7290.3
New Anseong 7	765	New Seosan 7	765	-1354.3	-116.1	1359.3	7290.3
West Seoul 3	345	Cheongyang 3D	345	800.3	55.7	802.2	2191.8
West Seoul 3D	345	Cheongyang 3	345	958.6	126	966.8	2191.8
New Yongin 3	345	New Jincheon 3	345	261.7	33.4	263.8	1095.9
New Yongin 3	345	New Jincheon 3	345	261.7	33.4	263.8	1095.9

Table 3. Real power flowing between the Yeongdong Area and Capital Area

Bus	Volt.	Bus	Volt.	From MW	From Mvar	From MVA	Lim MVA
East Seoul 3	345	New Jecheon 3	345	745.8	102.2	752.8	2191.8
East Seoul 3D	345	New Jecheon 3	345	731.5	95.1	737.6	2191.8
New Gapyeong 7	765	New Taebaek 7	765	1190.7	59.9	1192.2	7960
New Gapyeong 7	765	New Taebaek 7	765	1190.7	59.9	1192.2	7960

As mentioned above Table 2 and 3, the real power bound for Capital Area is 11308 MW, adding the real power flowing between the Jungbu Area and Capital Area and the real power flowing between the Yeongdong Area and Capital Area. It is showed that more than 50% of Capital Area loads are provided with the electric power from Jungbu Area and Yeongdong Area. According to the electric demands are forecasted to increase continuously, the real power bound for Capital Area will also increase. moreover, the 765 kV transmission lines will be increasingly in charge of providing the electric power to Capital Area. Therefore, It is required that the prevented method on unplanned events such as outages of the 765 kV transmission lines to provide the stability of the power system be prepared. In the case of the outage in the 2 circuits of the 765 kV transmission line between the New Anseong 7 and New Seosan 7, the results of load flow are also not converged. So, When the transmission line is outaged, the real power of the main transmission lines is unknown. In order to know the real power of the main transmission lines, the line flows in the steady-state and the contingency-state after equal 5% curtailments in buses of Capital Area loads are analyzed. The results are presented in Table 4 and 5.

Table 4. Steady-state line flows in 5% curtailments of Capital Area loads

Bus	Volt.	Bus	Volt.	From MW	From Mvar	From MVA	Lim MVA
New Gapyeong 7	765	New Taebaek 7	765	-1160.1	-48.9	1161.1	7960
New Gapyeong 7	765	New Taebaek 7	765	-1160.1	-48.9	1161.1	7960
East Seoul 3	345	New Jecheon 3	345	-694.3	93.6	700.6	2191.8
East Seoul 3 D	345	New Jecheon 3	345	-680.2	86.5	685.7	2191.8
New Anseong 7	765	New Seosan 7	765	-1301.8	-89.2	1304.8	7290.3
New Anseong 7	765	New Seosan 7	765	-1301.8	-89.2	1304.8	7290.3
Hwaseong 3	345	Asan 3D	345	-1108.1	192.1	1124.6	2191.8
Hwaseong 3D	345	Asan 3	345	-1179.5	218.2	1199.5	2191.8
West Seoul 3	345	Cheongyang 3D	345	-705.3	34.9	706.1	2191.8
West Seoul 3D	345	Cheongyang 3	345	-905.3	120.5	913.3	2191.8
New Yongin 3	345	New Jincheon 3	345	-186.3	23.5	187.8	1095.9
New Yongin 3	345	New Jincheon 3	345	-186.3	23.5	187.8	1095.9

Table 5. Line flows in contingency

Bus	Volt.	Bus	Volt.	From MW	From Mvar	From MVA	Lim MVA
New Gapyeong 7	765	New Taebaek 7	765	-1186.6	-91.9	1190.2	7960
New Gapyeong 7	765	New Taebaek 7	765	-1186.6	-91.9	1190.2	7960
East Seoul 3	345	New Jecheon 3	345	-781.9	81.4	786.2	2191.8
East Seoul 3D	345	New Jecheon 3	345	-759.1	70.8	762.4	2191.8
Hwaseong 3	345	Asan 3D	345	-1767	438.5	1820.6	2191.8
Hwaseong 3D	345	Asan 3	345	-1910	489.2	1971.7	2191.8
West Seoul 3	345	Cheongyang 3D	345	741.3	6.2	741.3	2191.8
West Seoul 3D	345	Cheongyang 3	345	-1144.2	194.3	1160.6	2191.8
New Yongin 3	345	New Jincheon 3	345	546.9	101.1	556.1	1095.9
New Yongin 3	345	New Jincheon 3	345	546.9	101.1	556.1	1095.9

In the case of the outage in the 765kV transmission lines between the New Anseong and New Seosan, the 345kV transmission lines between the Hwaseong and Asan are congested and the voltage stability is not stable. In order to make the power system be stable load shedding is required in the Capital Area. Direct Load Control Program has reserved interruptable load 367MW by contract with customers in the capital area. As the result of the proposed algorithm, the amount of load shedding is 211.8MW to manage the emergency of the 765kV transmission line outage. Line flows after the load shedding are presented in Table 6.

Table 6. Line flows with the load shedding algorithm

Bus	Volt.	Bus	Volt.	From MW	From Mvar	From MVA	Lim MVA
New Gapyeong 7	765	New Taebaek 7	765	-1217.2	-136.3	1224.8	7960
New Gapyeong 7	765	New Taebaek 7	765	1217.2	136.3	1224.8	7960
East Seoul 3	345	New Jecheon 3	345	833.4	71.7	836.4	2191.8
East Seoul 3D	345	New Jecheon 3	345	-809.6	61.4	812.0	2191.8
Hwaseong 3	345	Asan 3D	345	-1841.4	384.7	1881.2	2191.8
Hwaseong 3D	345	Asan 3	345	-1972	426.9	2017.7	2191.8
West Seoul 3	345	Cheongyang 3D	345	-827.9	30.3	828.5	2191.8
West Seoul 3D	345	Cheongyang 3	345	-1193.3	165.3	1204.7	2191.8
New Yongin 3	345	New Jincheon 3	345	-611.7	89.2	618.2	1095.9
New Yongin 3	345	New Jincheon 3	345	-611.7	89.2	618.2	1095.9

4. Conclusions

The load shedding algorithm is proposed to solve the transmission congestion problems in emergency from major outages. In the proposed method, the contracted loads with customers by a Direct Load Control Program are used for load curtailments. In order to demonstrate the effectiveness of the proposed algorithm, it has been tested on the power system of KEPCO. Test results show that the proposed algorithm provides the minimal amounts of interruptible load to operate the power system normally solving the transmission congestion at the specific line corresponding to the major outage.

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