Study on the Improvement of the Special Protection Scheme (SPS) in the Korean power system

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***Abstract*--This paper deals with the improvement of the special protection scheme (SPS) which has been applied to the low probability and high impact contingencies in the Korean power system since 2004. Simulation results about the recent event occurred on 765kV lines show that the current setting values of the SPS have to be revised and enhanced.**

In addition, by applying response-based undervoltage load shedding (UVLS) schemes with multi-step to severe contingencies in the system, we can have more effective results than those of the existing SPS. A centralized and a distributed UVLS schemes are considered in the simulation. ULTC based load recovery models and over excitation limiters (OXL) for the Korean power system are also included in the long term voltage stability analysis.

***Keywords*: Special Protection Scheme, Under Voltage Load Shedding, Voltage Stability Analysis.**

I. Introduction

As the last resort to avoid a voltage collapse, undervoltage load shedding (UVLS) is one of the very special protection schemes. Therefore, it should be applied very carefully in situations where voltage collapse might occur to prevent a blackout.

In the Korean power system, the SPS has been applied to a set of interconnected transmission lines between Seoul metropolitan area and non-metropolitan area since 2004. It was designed for secure operation of power system in Korea and for increasing interface flow limits as well.

The Korean power system is peculiar in that a large majority of the load is situated around Seoul metropolitan area. Generators with relatively low generation cost are mostly located in the southern coastal part of Korea (about 80%) while loads are heavily concentrated in the Seoul metropolitan area (about 42%) which is located in the northern part. It is the reason why a large amount of active power flows come from the south to north.

For the purpose of transferring the power, two parallel 765kV transmission lines and four 345kv parallel lines are used as interface transmission lines (see Fig. 1). The purpose of SPS we have applied is to increase the limit of the interface lines in case of outages of the 765kV lines. An outage of one of two parallel 765kV transmission lines and violation of the threshold voltage on a pilot bus during 200 milliseconds trigger the SPS on to shed approximately 1,000MW loads which are designated in advance.

However, the unexpected event in 765kV transmission lines recently occurred gives us the need to improve the existing SPS because the setting value of a supervising voltage to be operated is relatively high and the delay time of under voltage relay is too short. This paper shows the simulation results for this event and the necessity to improve the existing SPS in order to prevent the fast voltage collapse of the system.

In addition, by applying response based UVLS with multi-step load shedding schemes to the severe contingencies, it is shown that amount of load to be shed can be smaller than that of the current single-step SPS. The threshold voltages and amount of load to be shed in each step are simply used as the ones introduced in the paper [1]. And a centralized and a distributed UVLS scheme are also considered in the long term simulation. ULTC based load recovery models and over excitation limiters (OXL) for the Korean power system are included in the long term voltage stability analysis.

II. Review of current SPS logic in the system

A. The current single-step SPS logic

The current SPS has been designed to operate during extreme contingencies including the loss of one of two 765kV double circuit lines in load pocket area (Seoul).

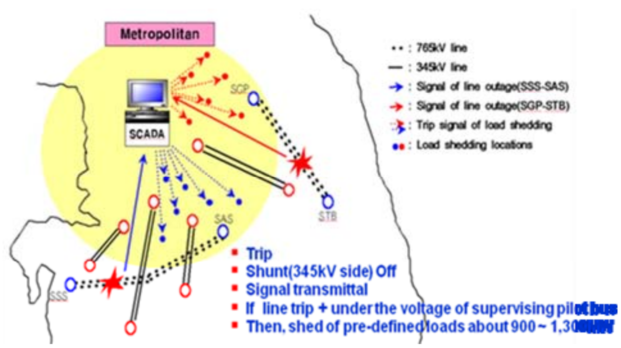

Fig. 1. Special Protection Scheme in the Korean power system

Line trippings are detected by operation of transmission line protective relays. This signal is transmitted to the SCADA

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system in regional control centers.

On the other hand, there are two 345kV pilot buses for supervising purpose. When one of bus voltages is lower than 340kV (0.986p.u.) during 200 milliseconds, the under voltage relay is operated to send the signal to the same SCADA system.

If these two conditions are satisfied, the predefined loads, which are the same as UFLS, are shed with single-step to prevent voltage collapse of the system (see Fig.1). The amount of load to be shed is 900 MW and 1,300MW respectively.

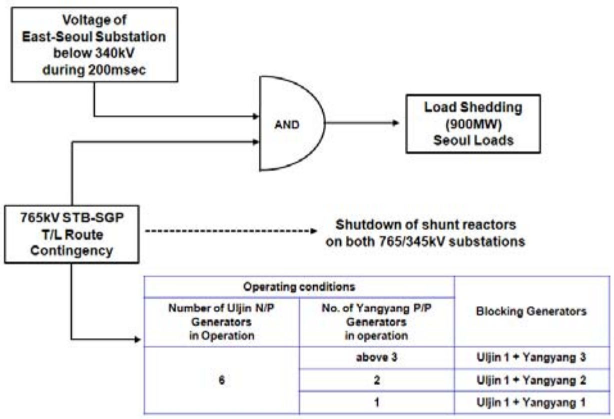

Fig. 2. The logic for current SPS

Fig. 2 demonstrates the summarized logic of current SPS in the system. In the figure, blockings of the related generators are for maintaining transient stability of the system.

B. Simulation results for the recent event

Recently, unexpected line tripping event was occurred on 765kV transmission lines because of unstable DC source voltage for protective relays in STB S/S. Four circuit breakers on both 765kV transmission lines were opened not because of fault (see Fig. 3).

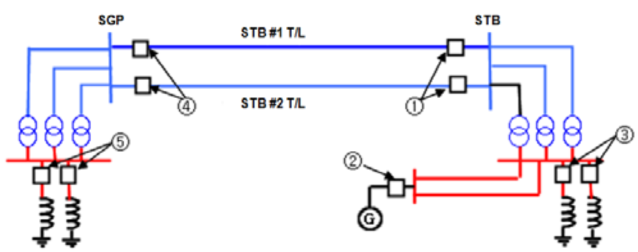

Fig. 3. System diagram for 765kV/345kV substations

At the time, very fortunately, no predefined loads about 900MW were shed because duration time below 340kV on the supervising pilot bus (East-Seoul) was not over than 200 milliseconds. Fig.4 shows the simulation result of voltage on the bus when the event occurs. Initially, the CBs at STB bus are opened (step 1 in Fig. 3) and one nuclear generator is out (step 2) for maintaining transient stability of the system. After 900 milliseconds, the CBs for the shunt reactors on 345kV bus (step 3) are opened. Because the voltage on the pilot bus at this point is 342kV, slightly over 340kV, the SPS cannot be operated. When the CB opened at SGP bus (step 4 in Fig. 3), the voltage is dropped to 336kV, which is below 340kV. But duration time below 340kV is no more than 200 milliseconds. Load shedding does not occur in this case. However, if the system is heavily loaded, that is six nuclear generators are in operation, the SPS can be operated to shed the predefined loads even though it is not the fault case (see Fig.5). When line outages result from a fault are occurred and CBs are opened at the same time, the voltage of pilot bus goes down far below 340kV during 750milliseconds (see Fig. 6). Then, the SPS is expected to be operated properly.

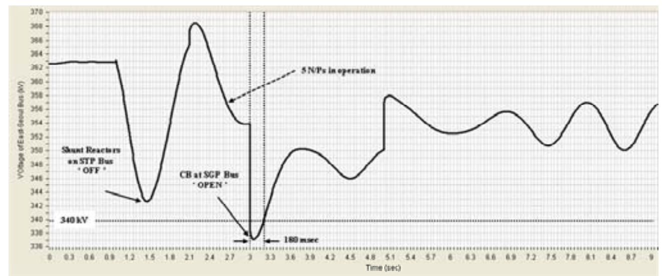

Fig. 4. The voltage of East-Seoul pilot bus when unexpected line trippings (5 Nuclear Generators in operation)

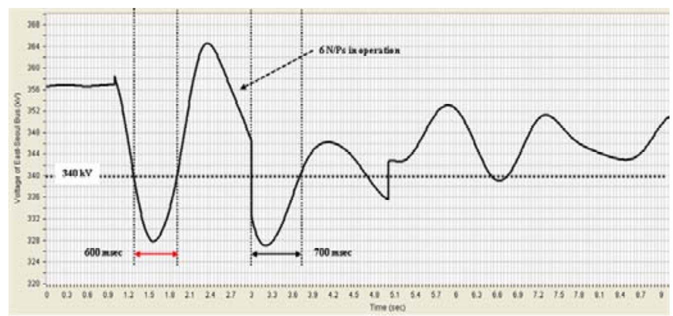

Fig. 5. The voltage of East-Seoul pilot bus when unexpected line trippings (6 Nuclear Generators in operation)

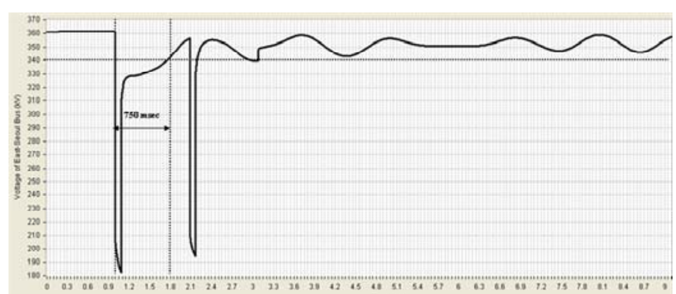

Fig. 6. The voltage of East-Seoul pilot bus when line outages (5 Nuclear Generators in operation)

Through the simulation results above, we can say that setting values of the current SPS should be considered to change. The voltage magnitude on the pilot bus for reference, 340kV, is too high and the delay time of under voltage relay, 200 milliseconds, is too short. P-V curves we analyzed on East-Seoul bus for several system conditions (not shown in the paper) say that collapse voltage to be evaluated is below 326 kV. In addition, as it can be seen in Fig. 4 ~ Fig. 6, the delay time of under voltage relay to be operated can be expanded to one or two seconds because system collapse will not be happened within several seconds even under severe conditions. If the setting values are changed to these levels, we will not worry about the loss of loads result from this kind of unexpected events. In order to set the final values of the SPS, however, more extensive and rigorous studies under various system conditions are needed.

III. Application of UVLS with Multi-Step Scheme to Current SPS

A. System models to be considered in the simulation

In order to apply undervoltage load shedding with multi-step scheme to current SPS in the system, long-term voltage stability analysis in the time domain is necessary. The system models with long-term dynamics such as OXL (Over eXcitation Limiter) of generators, load recovery models, switched shunt compensation etc. should be considered in detail when simulation [2, 3]. In the paper, basic OXL models by Van Cutsem [4, 5] and ULTC-based load models recommended by IEEE [8] are simply used in the simulation because the exact dynamic models of them can only be derived from field test. Fig. 7 represents the ULTC load recovery model which is included in the simulations.

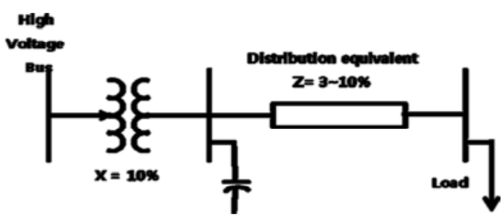

Fig. 7. The ULTC-based load model recommended by IEEE [8]

The OXL is to protect the exciter in each generator. Exciters can normally raise exciter voltage up to the ceiling point, which is the value about 200% of their current ratings, to maintain terminal voltage constant for transient stability after faults. However, since the current cannot be maintained continuously with this level, OXL reduce the level of 120% of nominal value within the designated time. If OXL models are not used in the simulation, all generators in the system can produce the exciter currents up to the ceiling points. Then, amount of reactive powers generators can produce are over than real values. Therefore, the models should be considered to get the correct results in the long-term simulation of voltage stability analysis.

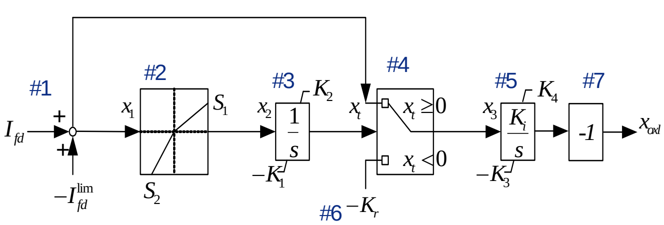

Fig. 8. The Over eXcitation Limiter model (OXL) used in the simulation.

In the OXL model given in Fig. 8, the most important parameter is the limit (max) value of the field current of generator. Because it should be derived from field test of the generator and excitation system, the approximate value calculated by the below equation (1) representing Fig. 9 is used in the simulation. Equation (1) and Fig. 9 can be derived from EPRI's VSTAB report [9].

$$I_{fd,\max} = \frac{X_s}{V_t X_{ad}} \left| P_{\max} + j\left(Q_{\max} + \frac{V_t^2}{X_s} \right) \right| \quad (1)$$

Where, $X_s = X_q,\ X_{ad} = X_d - X_l$

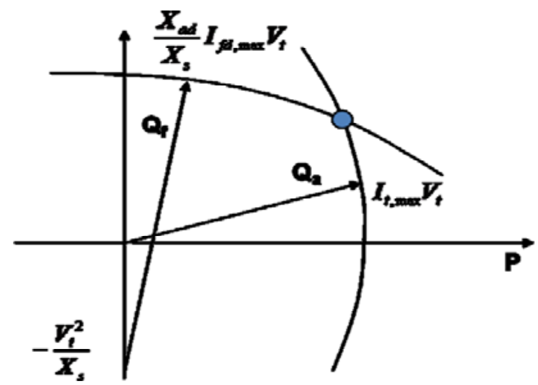

Fig. 9. Determination of the approximate value of $I_{fd,\max}$.

For the UVLS model, '*LVSHBL*' bus load shedding with 3 step model in PSS/E, PTI was used in the simulation. All the system data in the Korean system was changed to have transformer with ULTC between 154kV bus and 22.9kV load. The OXL model was also considered as the user-defined model in TSAT (Transient Stability Assessment Tool, by PowerTech Inc., Canada), which is given below.

```
21921,'OELUDM',1 /DEVICE IDENTIFICATION
0 /REMOTE BUS
0 0 0 /REMOTE BRANCH
1,'BLK1','SUM' /CONTROL BLOCK 1
2,'BLK2','NLF',-10,-20,-5,-10,-1,-2,0,0, 1,1,10,10 /CONTROL BLOCK 2
3,'BLK3','IN',1.0,10.0,-10.0,0.0 /CONTROL BLOCK 3
4,'BLK4','LSW',0.0,0.00,0.00 /CONTROL BLOCK 4
5,'BLK5','IN', 1.00, 0.10,-0.10,0.0 /CONTROL BLOCK 5
6,'BLK6','SUM' /CONTROL BLOCK 6
7,'BLK7','GN',-1.0,0.0,0.0 /CONTROL BLOCK 7
1,2, 2,3, 1,4, 6,4, 3,-4, 4,5, 5,7 /BLOCK INTERCONNECTION
1,'IFD'1.0,1,'CONT',   -2.452,6,'CONT',0.0  /BLOCK INPUT
7 /BLOCK OUTPUT
```

In the user-defined model above, the numbers indicate the number of control blocks represented in Fig. 8.

B. Validation of models used in the simulation

Fig. 10 and Fig. 11 represent the load recovery characteristic by ULTC-based load modeling in the long-term simulation. No UVLS schemes are applied for validating load recovery models used in the simulation after one of 765kV double-circuit lines is out (SGP-STB in Fig. 3). After around 100 seconds, the system voltage (East-Seoul bus) goes down to a different operating condition with loads recovered (Fig. 10). Fig. 11 indicates the amount of MW loads recovered on Nowon bus, on which the load recovery models applied.

In addition, the output of an OXL model block of a gas turbine generator in the system is shown in Fig. 12. After a critical contingency, the generator cannot produce the reactive power more than its maximum because of the operation of

OXL.

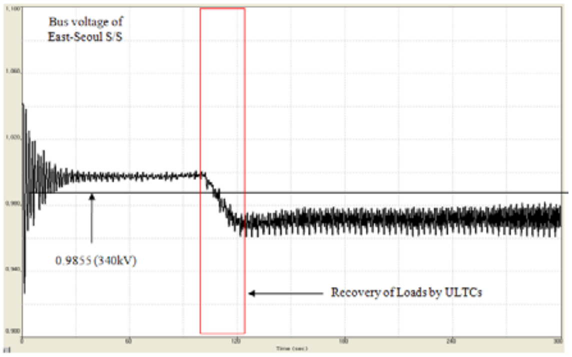

Fig. 10. Load recovery characteristic by ULTC-based models. (The bus voltage of the pilot bus (East-Seoul))

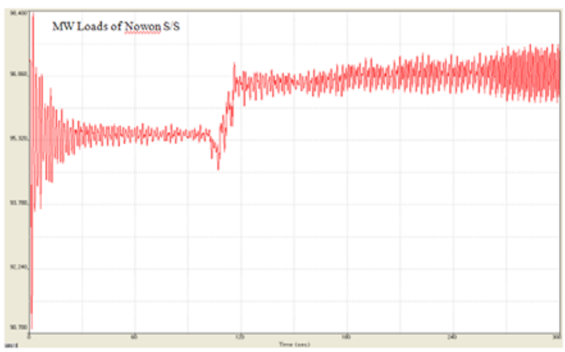

Fig. 11. Load recovery characteristic by ULTC-based models. (The amount of MW loads on the load bus (Nowon))

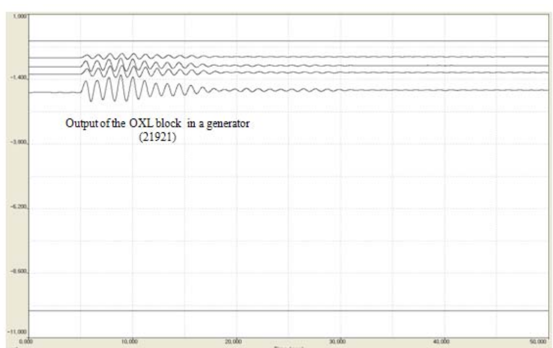

Fig. 12. The output of OXL block in a generator after a critical fault.

C. Simulation results for UVLS with multi-step scheme

In the simulation, the UVLS with multi-step scheme we applied is as follows.

■ A distributed UVLS Scheme

For the same critical contingencies as used in the current SPS in the system, a kind of distributed UVLS with multi-step schemes is applied (see Fig. 13) in the simulation. Compared to the current SPS, there are no supervising pilot buses in the system. The individual voltages of buses to be shed loads are monitored for operation of UVLS. With a 765kV double line contingency, the voltages of the buses are lower than 4% of the lowest normal voltage with over 3.5 seconds delay, 20% loads are shed at each load buses, which are selected in advance. The delay times for the UVLS are the same one as in the paper [1].

- 20% of area load shed at voltage 4% below the lowest normal voltage with 3.5 seconds time delay
- 20% of area load shed at voltage 4% below the lowest normal voltage with 5 seconds time delay
- 20% of area load shed at voltage 4% below the lowest normal voltage with 8 seconds time delay

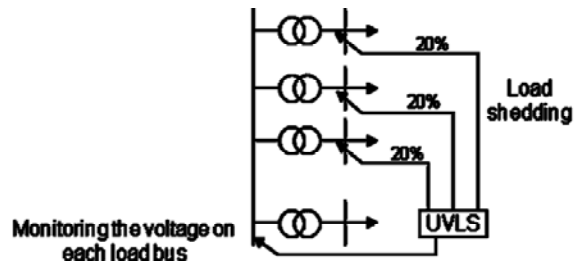

Fig. 13. The concept of the distributed UVLS applied in the simulation

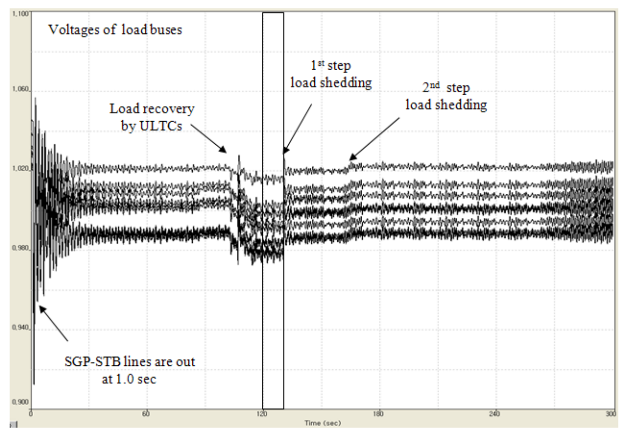

Fig. 14. The voltages of load buses to be monitored for shedding loads

TABLE I
THE AMOUNT OF LOAD TO BE SHED AND NUMBER OF STEPS WHEN APPLIED THE DISTRIBUTED UVLS SCHEME

Bus No.	Pload (MW)	No. of steps applied	Amount of MW load to be shed
1595	95.8	0	0
1565	96.7	0	0
1590	114.5	0	0
1545	66.8	0	0
1630	87.4	0	0
1765	94	2	33.8
1525	97.2	0	0
1530	153	0	0
1520	148.1	0	0
1580	58.3	0	0
1770	89.9	2	37.8
1845	69	0	0
1790	140.1	1	22.4
1670	102.6	2	18.5
1785	129.6	2	41.5
1635	86.8	2	39.9
1695	105.5	2	20
1680	131.2	2	27.6
1655	121.1	2	24.2
1745	141.4	2	17
1775	73.1	0	0
Total	2202.1		282.7

Fig. 14 shows the voltages on load shedding buses during SGP-STB line outage. The magnitudes of voltages are comparatively lower than those of the current SPS. And not all of the load buses are operated to shed the loads because the voltages of the buses are raised by the load shedding on the near bus (see Table I).

■ A centralized UVLS Scheme

In this paragraph, 'centralized UVLS' means the information needed to operate UVLS is gathered into the one central unit and it sends the signal to shed the predefined loads.

It is the very similar way to shed the loads for the current SPS in the Korean system other than multi-step shedding scheme. Fig. 15 represents the centralized UVLS scheme applied in the simulation.

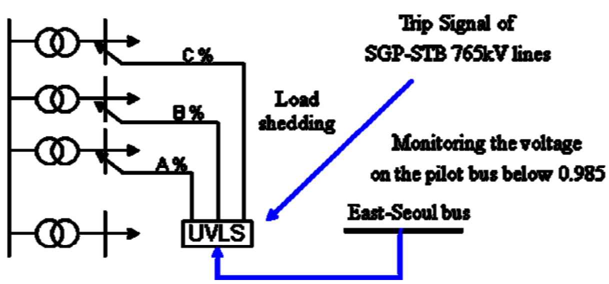

Fig. 15. The concept of the centralized UVLS applied in the simulation

The scheme applied for the simulation is as follows.

- 1st step of UFLS loads shed at below 340kV (0.985 p.u.) on the pilot buses with 3.5 seconds time delay
- 2nd step of UFLS loads shed at below 340kV on the pilot buses with 5 seconds time delay
- 3rd step of UFLS loads shed at below 340kV on the pilot buses with 8 seconds time delay

Fig. 16 shows the bus voltage on East-Seoul with the loss of SGP-STB lines. If the voltage is lower than 0.985 p.u. with over 3.5 seconds time delays after 765kV line trippings, then 1st step of UFLS (Under Frequency Load Shedding) loads are shed. No further load shedding after the 1st step is occurred in this case because the pilot bus voltage is raised up to over 0.985 p.u. Table II summarized the amount of loads to be shed and the steps on each load buses.

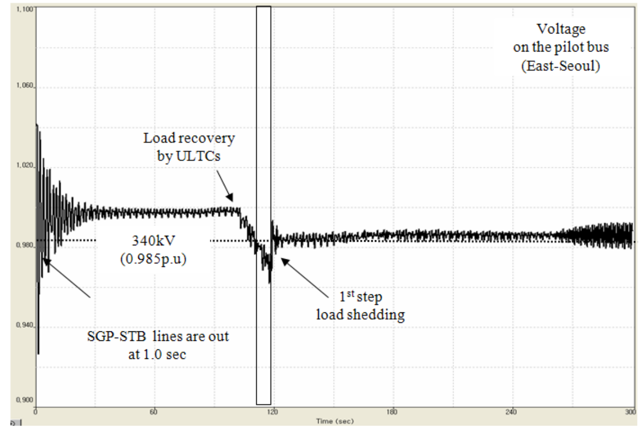

Fig. 16. The voltage on the pilot bus (East-Seoul) to be monitored.

TABLE II
THE AMOUNT OF LOAD TO BE SHED AND NUMBER OF STEPS WHEN APPLIED THE CENTRALIZED UVLS SCHEME

Bus No.	Pload (MW)	No. of steps applied	Amount of MW load to be shed
1595	95.8	1	6.7
1565	96.7	1	17.4
1590	114.5	1	26.3
1545	66.8	1	9.4
1630	87.4	1	10.5
1765	94	1	16.9
1525	97.2	1	28.2
1530	153	1	7.7
1520	148.1	1	7.4
1580	58.3	1	10.5
1770	89.9	1	19.8
1845	69	1	9
1790	140.1	1	22.4
1670	102.6	1	9.2
1785	129.6	1	20.7
1635	86.8	1	20
1695	105.5	1	10.6
1680	131.2	1	14.4
1655	121.1	1	12.1
1745	141.4	1	8.5
1775	73.1	1	6.6
	2202.1		294.3

IV. CONCLUSIONS

Through the simulations, we've known that the setting values of current SPS are needed to be revised. The reference voltage of pilot buses should be lowered to below 326kV and the delay time of UVR can be expanded to one or two seconds.

At the same time, we can consider the application of UVLS with multi-step scheme to the current SPS in the system. As it can be seen in the paper, the application of the UVLS with multi-step scheme, both distributed and centralized, could reduce the amount of load to be shed significantly compared to the amount of load to be shed for the current SPS with single-step, about 900MW. In order to set the final values of the SPS or UVLS with multi-step scheme, however, more extensive and rigorous studies under various system conditions are needed.

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