Investigation for new solutions for mega city power grid issues

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Abstract

With the fast development of mega city power grid, new challenges are more and more pressing, especially huge short current and voltage stability. In this paper, two solutions based on new technologies are proposed. The first solution is consisted of DYNACURs (a new short circuit current limiting device) and SVC Lights (ABB's STATCOM). Another is consisted of HVDC Light and a small DYNACUR. The schemes and corresponding performance are investigated based on a mega city power grid similar to Shanghai. The results show that both of them are effective solutions. For approximate performance, the cost is compared and the proper situations of them are discussed respectively.

Keywords: Short Circuit Current, Voltage stability, DYNACUR, SVC Light, HVDC Light

1 INTRODUCTION

Mega city-infeed issues are arising in those mega cities in China, such as Beijing, Shanghai & Guangzhou, which are featured with typical heavy loading, huge short circuit current and stringent environmental code. Fast increasing load and its density make the short circuit current higher and higher[1~3]. Meanwhile, a great deal of air conditions make transient voltage support in city center more necessary[4][5]. However, because of the limited area and strict environmental requirement, it is inevitable to remove the power plant in city center and import power over long distance. For example, power import of electricity from outside the city has contributed two thirds of the whole electricity consumption in Beijing, while short current level in Shanghai will reach 63kA[1~3], the largest current existing breaker can handle. The high short circuit current has prevented the expanding of power grid to meet fast increasing load[3]. Generally, high short circuit current, voltage stability and feeding bulk power into city center are special big challenges of mega cities.

Higher and higher voltage levels are introduced into the urban area recently and underground substations plus AC cables are also used to minimize environmental issues and requirement of right of way[6]. Network partition scheme is widely adopted to restrain uprising short circuit current level[2][3]. 220 kV system of Beijing power grid are divided into East sub area and West sub area, and that of Shanghai power grid is divided into seven parts. Series reactor is also considered[7]. However, such conventional methodologies are reaching their capability limits in solving these mega city issues, and other economical and effective alternatives are expected.

This paper is oorganized into three parts. In part one, the studied system is described briefly. Both the problems to be solved and the requirements of solutions are defined. Solution A consisted of DYNACUR and SVC Light is provided and solution B consisted of HVDC Light and small DYNACUR is provided in part two. Firstly, the characteristic of the new technologies is introduced. Then, the configuration, parameters and corresponding results of the solutions are illustrated. In part three, costs of these solutions are estimated and compared with each other. Impacts on power grid development and the proper situations of them are discussed respectively.

2 Studied system and problem definitions

A real city power grid similar to Shanghai is utilized to study the solutions. In the following text, it is called Shanghai power grid.

The main grid frame of this grid is 500KV double loop. To decrease the short circuit current, 220KV system is divided into several sub-area, as shown in figure 1.

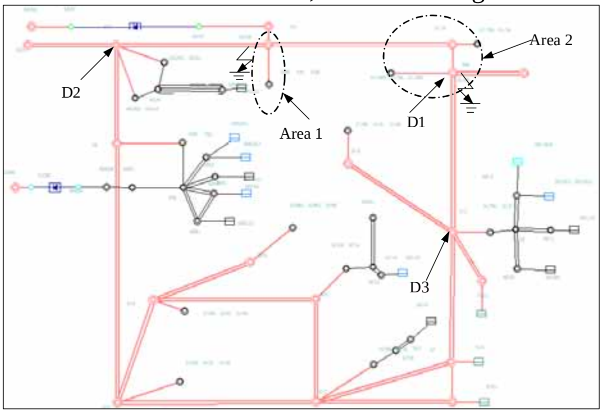

Figure 1 Shanghai Power Grid

In this grid, three phase fault current of several 220KV buses still exceeds 50KA and that of several 500KV buses exceeds 55KA, which are listed in Table 2.

Because of the splitting, two 220KV sub-areas without large capacity generator are lack of transient voltage support. As a result, the voltages will not recovery when severe faults occur, which are listed as follows and the voltage response curves of sub area 1 are shown in Figure 2.

1. In sub area 1 as shown in figure 1, One 500 kV line in the left halts, A 3 phases permanent grounding fault occurs at the beginning of the bus line and it is cleared after 0.1 second. The voltage of sub area 1 can’t recovery and is lower than 0.8 p.u durative, then, commutation fails in neighboring DC converter, which cause voltage depression.
2. In sub area 2 as shown in figure 2, one 500 kV line in the right halts, A 3 phases permanent grounding fault occurs at the beginning of the bus and it is cleared after 0.1 second. The voltage of sub area 2 can’t recovery and is lower than 0.8 p.u.

In network data, the generator model includes sub-transient inductance, exciter and governor. Half of total load is modeled as inductive motor and the other is constant impedance, which simulates the load in summer peak.

In this paper, solutions focus on the problems defined above. To evaluate and compare the performance of solutions. Two basic requirements for the solutions are defined as follows.

- ✓ The short circuit current of 500KV bus is lower than 50KA and that of 220KV bus is lower than 42KA.
- ✓ The voltage of sub area 1, sub area 2 can recovery to 0.8 p.u after clearing the fault in 1 second.

Also, the power grid that adopts proposed solution should satisfy the N-1 criteria.

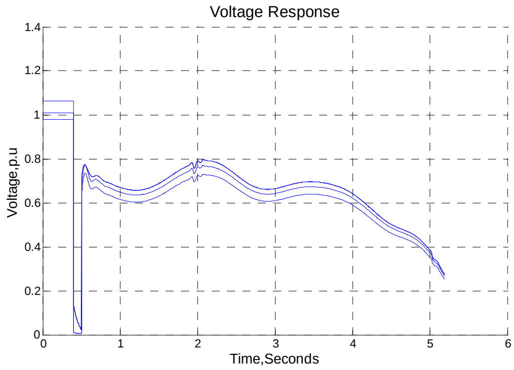

Figure 2 Voltage Responds of Sub area 1

3 Solution A

In this solution, high short circuit current and transient voltage stability are solve by two new devices, DYNACUR and SVC Light, respectively, which is describe in the following.

3.1 DYNACUR

The DYNACUR concept is built on ABB’s unique experience of FACTS devices. It is a combination of a series reactor and a series capacitor. The circuit is tuned to the fundamental frequency and thereby eliminates the problems of a pure series reactor. No influence on system stability, no load sharing problem and no voltage profile problem. Single line diagram is shown in Figure 3.

When a short circuit is detected the series capacitor is immediately bypassed by a fast protective device (FPD) and the short circuit current is limited by the series reactor.

The FPD consists of a combined Arc Plasma Injector and Fast Closing Contact for speed and reliability. Both units are fully encapsulated for maximum reliability also in adverse climate conditions.

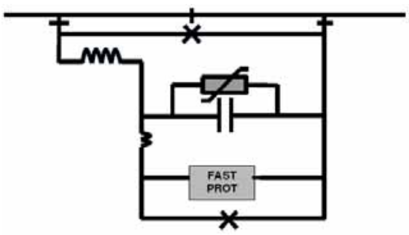

Figure 3. Single line diagram of DYNACUR

3.2 SVC Light

SVC Light is brand name of the ABB’s STATCOM. It can be seen as a voltage source behind a reactance.

Physically it is built as a three-level Voltage Source Converter (VSC) equipped with Insulated Gate Bipolar Transistors (IGBTs) that are controlled by Pulse Width Modulation (PWM).

VSC converts the DC voltage into a three-phase set of output voltages with desired amplitude, frequency, and phase. That means, SVC Light provides reactive power generation as well as absorption purely by means of electronic processing of voltage and current waveforms (the grid will see it as a synchronous machine without inertia). Therefore, it is specially suited for supplying full compensating current at very low AC network voltages and mitigates the impact of severe faults on the power system.

The STATCOM design features also include a minimum footprint and effective electro-magnetic screening. Both of them were required in the mega city power grid. In 2004, a ± 95Mvar SVC Light is used to replace the retired crucial generator in Austin[8], which is a typical application in city grid.

3.3 Configuration of Solution A

Through analyzing the distribution of short circuit current, it is found that about 50 percent short circuit current of 220KV bus comes from 500KV system and the other is contributed by the generators in 220KV sub area. Therefore, three DYNACURs are inserted into the 500KV double loop to reduce short circuit current of multi buses. The locations of them are shown in Figure 1. The connection pattern is bus connection, as shown in Figure 4. DYNACURs split a part of bus of 500kV connection lines and other bus including 500kV/220kV connection transformer, which decreases the 500kV system's contribution to 220kV bus obviously.

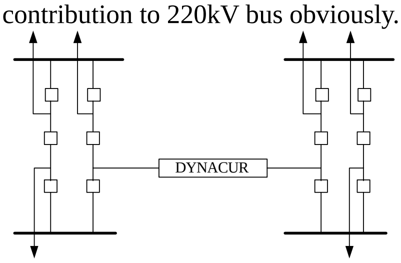

Figure 4 the configuration of DYNACUR

The startup condition of DYNACUR is over current. If the current though DYNACUR exceeds the preset value, the FPD will bypass the capacitor quickly. The response time of FPD is 2ms after fault is detected, which is slower than actual device. The DYNACURs' parameter listed in table 1 is design according to the requirements in section 2.

Table 1 Parameters of DYNACURs

Name	Voltage	Inductance	Capacitance
D1	500KV	25ohm	-25ohm
D2	500KV	10ohm	-10ohm
D3	500KV	10 ohm	-10 ohm

In solution 2, two SVC Light is installed on 35KV side of 500kV/220kV connection transformer in sub area 1 and sub area 2. The capacity of sub area 1 is ±120MVA and that of sub area 2 is ±80MVA which is minimum value to grantee voltage recovery.

Three phases short circuit currents of buses which short circuit current are higher than requirement in section 2 are listed in table 3, both with DYNACURs and without DYNACURs.

Table 2 3-phases short circuit current under solution A

BUS	Voltage	Without DYNACURs (kA)	With DYNACURs (kA)
S12	500KV	54.0937	47.685
S52	500KV	56.1414	42.099
S711	500KV	53.2473	48.382
S73	500KV	52.8999	47.455
S120	220KV	48.259	39.647
S12N1	220KV	49.552	40.715
S520	220KV	46.4889	39.850
S52N1	220KV	49.5889	41.795
S52N2	220KV	47.6326	40.540
S5N	220KV	47.0887	41.606

Figure 5 shows the voltage response of sub area 1 using solution A., and the voltage response of sub area 2 is similar.

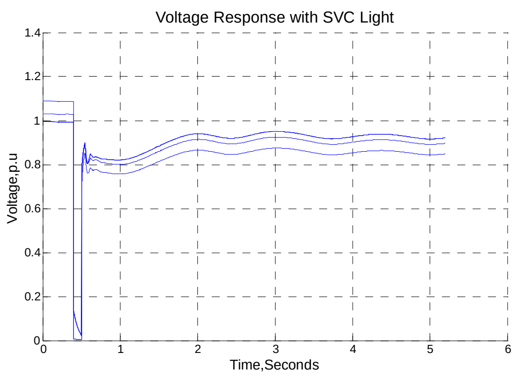

Figure 5. Voltage Response with SVC Light

From the result, solution A decreases the short circuit and improves the voltage stability as requirement.

Because the impedance of DYNACUR is almost zero in normal operation, it has little impact on operation and stability of the power grid, which is proved in N-1 validation. The configuration of protective rely also need not to be modified. The speed of it is similar to thyristor controlled series reactor but it is simpler and cheaper. It is one of best solution to reduce the short circuit current.

Because the output of SVC Light doesn't depend on the system voltage, it is very effective to satisfy the relative power requirement of motor load during re-startup period. The fast speed is also an important factor in this process. SVC or conventional capacitor is not so powerful when taking on this task.

4 Solution B

In this solution, both short circuit current and voltage support are solved using HVDC Light. A small DYNACUR is used to decrease the short circuit current of several 220kV bus in which the impedance of the reactor is 8ohm.

4.1 HVDC Light

HVDC Light is HVDC technology based on voltage source converters (VSCs). Back-to-back or combined With extruded DC cables, power ratings from a few tens of megawatts up to several hundreds of megawatts are available[9]. HVDC Light converters include insulated Gate bipolar transistors (IGBTs) and operate with high frequency pulse width modulation in order to achieve high speed and as a consequence small filters and independent control of both active and reactive power. HVDC Light cables have extruded polymer insulation. Their strength and flexibility make the HVDC Light cables well suited for severe installation conditions both underground as a land cable and as a submarine cable. The simple topology of HVDC Light is shown in Figure 6.

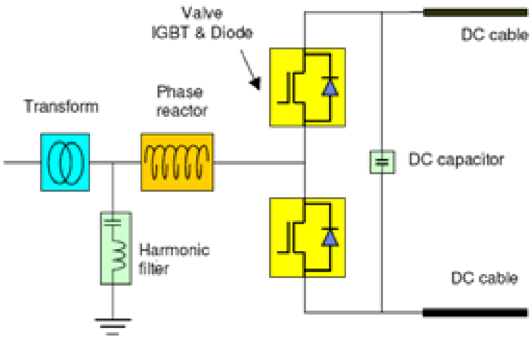

Figure 6. Single Diagram of HVDC Light

In an HVDC Light system the active and reactive power can be controlled at the same time like in a synchronous converter, but the control is much faster, in the millisecond range. This fast control makes it possible to create any phase angle or amplitude, which can be done almost instantaneously. Concerning voltage stability, HVDC Light converters can operate in STATCOM mode to provide fast transient voltage support. Because of the nature of HVDC system and VSC, HVDC Light has ability to limit short circuit current.

4.2 Configuration of solution B

The principles of solution B are similar to solution A. The short circuit current level is reduced through limiting short circuit current of 500kV system. The 500KV double lines between sub area 1 and sub area 2 are replaced by HVDC Light system. One target is to split the loop, then reduce short circuit current. The other target is to support voltage both sub area 1 and sub area 2 using converter station. The small DYNACUR is to reduce the short circuit current of several 220kV buses. The configuration is shown in figure 7.

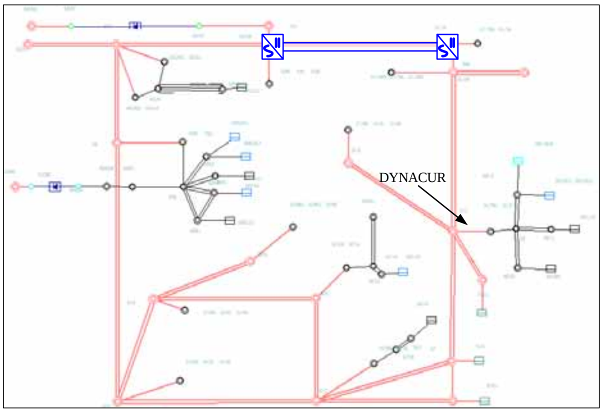

Figure 7 HVDC Light Solution

The parameters of them are listed in table 3, which also is minimum value to meet the previous requirement.

Table 3 HVDC Light's parameter

Component	Item	Value
HVDC Light	Sn	360MVA
	CosFI	0.89
	Voltage	$\pm$150KV
	Reactive power Control	Constant AC Voltage
DYNACUR	Reactor	8ohm
	Capacitor	-8ohm

Three phases short circuit currents are listed in table 4, both with HVDC Light and without HVDC Light.

Table 4 3-phases short circuit current under solution B

BUS	Voltage	Without HVDC Light (kA)	With HVDC Light (kA)
S12	500KV	54.0937	46.851
S52	500KV	56.1414	48.543
S7	500KV	53.2473	47.895
S711	500KV	52.8999	47.635
S120	220KV	48.259	39.452
S12N1	220KV	49.552	40.537
S520	220KV	46.4889	37.839
S52N1	220KV	49.5889	39.571
S52N2	220KV	47.6326	38.422
S5N	220KV	47.0887	41.280

Figure 8 shows the voltage response of sub area 1 with HVDC Light. Form the result, solution B also satisfies the requirement.

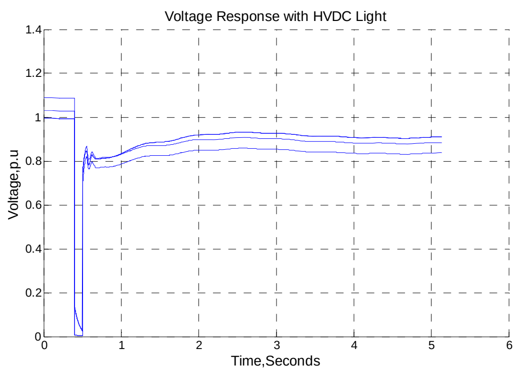

Figure 8. Voltage Response with HVDC Light

The introduction of HVDC Light transmission system cut off the channel of fault current in 500kV double loops. As a result, the apparent inductance of every generator is larger. Therefore, the short circuit current of all buses decrease.

The basic theory of HVDC Light's converter is same with SVC Light in terms of transient voltage support. The result is also similar.

5 Cost comparison

From the result, both solution A and solution B can effectively solve the problems which this paper focuses on and the performance of them is similar. For the investor, cost is one important factor. So cost of them is calculated. The cost of D2 in solution A is regard as 1 unit. Table 5 lists the cost of all components in solution A and solution B.

Table 5 Cost comparison

Solution A		Solution B	
Component	Price(p.u)	Component	Price(p.u)
DYNACUR(3)	5	HVDC Light	14.56
SVC Light(2)	3.75		
AC line	1.53*	DYNACUR	0.8
Total	10.28	Total	16.16

**AC line means the 500KV double circuit replaced by HVDC Light transmission system. This cost of it is estimated according to Chinese price and others are estimated according to existing project in the world.*

The cost of solution B is about 50% higher than solution. But the cost only includes equipment. If the cost of installation, space and environmental are considered, the difference of them will be smaller for HVDC Light need less space and is environmental friendly, which is expensive in mega cities. But this part of cost is different in different place, so it isn't considered.

Solution A can be seen as a surgical on mature power grid. In this kind of power grid, it is difficult to change the mainframe of the grid. The configuration of solution A is very flexible, so it is suit to enhance weaken points in various mega city power grids. The environmental friendly and mini footprint is also absolutely necessary in mega cities.

Solution B, mainly HVDC Light, is thorough new technology to existing power grid. It introduces a flexible and controllable part into pure AC grid which benefits system stability control and optimal operation. This paper only utilizes a part of its advantages. There are many excellent characteristic which are list in the following.

- ✓ Black start which was verified in the 2003 blackout, the newly installed HVDC Light in Cross Sound Project is crucial to the black start of long island.
- ✓ Feeding bulk power into city center and support voltage[11]. Because the AC cable capacitance limits the practical cable length, it may be the only choice where the corridors are difficult or environmental requirement is strict.
- ✓ Power flow modulation and oscillation damping.

If it is taken account in when constructing mega city grid, many problem in pure AC grid will not occur. So it will bring a new concept city grid.

5 Conclusion

To solve the problems in mega city, this paper propose the solutions that utilize DYNACUR, SVC Light and HVDC Light. Through the simulation using shanghai power grid, both of them are effective. The cost is compared and the proper application of them is discussed.

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Biographies

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Staffan Rudin has a Master Degree in Electrical Engineering from the Institute of Technology Lund, Sweden. Mr. Rudin has 15 years of experience in the Power T&D subarea. This includes development and design of both FACTS and HVDC systems. Mr. Rudin previously held a position as Manager of the ABB FACTS System Design group in Sweden. His current position at ABB is Marketing Manager HVDC Light och & FACTS in China.