The Simulation of Voltage Control for Impact Load by the Parallel FACTS with Energy Storage

Y Ren1,3, D Zhang1,3, X T Li1,3 and B Z Liu2,3

1Electric Power Research Institute, State Grid Ningxia Electric Power Co., Ltd., Yinchuan, China
2School of Electrical and Electronic Engineering, North China Electric Power University, Beijing, China
3visayw@126.com, aelict@vip.sina.com, lee_abner@126.com, bzliu@ncepu.edu.cn

Abstract. Voltage level is one of the most important indicators in the operation of power systems. This paper proposes a method for suppressing voltage fluctuations in the grid with impact load using parallel FACTS with energy storage. This paper first analyzes the reasons of the voltage over-limit and voltage fluctuation of the actual grid - SZ grid, then points out the lack of voltage adjustment means in the actual operation. The parallel FACTS with energy storage mathematical model is given, and the controller structure of this kind of device is analyzed. By adding the parallel FACTS with energy storage to the SZ grid and using the actual operating data to carry out simulation calculations, the calculation results show that the use of parallel FACTS with energy storage has a good inhibitory effect on the voltage fluctuation and voltage over-limit problem, which can be used as a new voltage control method for the SZ grid planning and operation.

1. Introduction
In order to promote economic development, many cities in China have vigorously developed high-energy-consuming industries, and the number of high-energy-consuming enterprises with impact loads such as electric arc furnaces has increased dramatically. These enterprises have driven local economic development, but they have also brought significant power quality problems, such as harmonic currents, voltage fluctuations[1].

Reactive power compensation technology can effectively improve the power supply capacity of power system equipment, improve voltage quality, reduce user electricity expenses, promote the safe, effective and economic operation of power systems, bringing power systems and users huge economic benefits. Studying reasonable reactive power compensation technology is of great significance for dealing with power quality problems of power systems with impact loads[2].

In order to solve the problem of voltage violation of the distribution network caused by high penetration of renewable resources, Ref [3] proposed an active-reactive coordinated optimization method considering the regulation effect of energy storage. For the difficulties of dynamic voltage quality control in substation, distribution static synchronous compensators (D-STATCOM) are used. The method realizes the simultaneous compensation steady state for voltage regulation and impact load harmonics and reactive power[6][7]. For the voltage/reactive control of Shizuishan grid, Ref [4][5] analyzes the allocation and operation situation of reactive power compensation for the large
consumer of Shizuishan power grid, puts forwards measures and suggestions of reactive power operation management for the large consumer.

With the development of power electronics technology, the application of flexible AC transmission system (FACTS) in power systems has become popular. The use of FACTS devices to achieve damping control has become an effective measure to improve system safety. The parallel FACTS with energy storage can quickly absorb or release the active power and reactive power synchronously, and improve the controllability of the FACTS for the power system[8].

This paper analyzes the reasons of the voltage over-limit and voltage fluctuation of the actual grid - SZ grid, and points out the lack of voltage adjustment means in the actual operation. The parallel FACTS with energy storage mathematical model is given, and the controller structure of the device is analyzed. By adding parallel FACTS with energy storage to the SZ grid and using the actual operating data to carry out simulation calculations, the calculation results show that the use of parallel FACTS with energy storage has a good inhibitory effect on the voltage fluctuation and voltage over-limit problem, which can be used new reference for the SZ grid planning.

2. Bus voltage problem analysis of SZ Power Grid

The electric load structure of SZ Power Grid is dominated by high energy consumption (iron alloy, calcium carbide, silicon carbide) and large industries (including steel, non-ferrous metals, chemicals, mono-crystalline silicon, building materials, etc.), accounting for 94.05%. The load level is greatly affected by the market conditions. Therefore, affected by the industrial production cycle and process, the load fluctuates significantly at the three time points of 8:00, 16:00, and 0:00 every day, and the voltage fluctuation amplitude is large. Ref [4][5] analyzes the operation characteristics of Shizuishan Power Grid and the operation of large-scale reactive power compensation equipment. It points out the impact of the reactive power management of Shizuishan Power Grid, and puts forwards some measures and suggestions for regulating the reactive power operation of large users.

There are a large number of high-energy-consuming enterprises in SZ power grid, especially smelters that use electric arc furnaces. As a kind of important load in the power system, the impact of large-scale electric arc furnace on the system is more and more obvious. On the one hand, it has higher requirements on power supply reliability. The production scale of electric arc furnace is continuously expanding, and the equipment capacity is constantly increasing. But the adverse effects of electric arc furnaces are becoming more and more obvious.

2.1 Concentrated-connected High-energy-consumption load cause the large voltage fluctuation

Due to the economic transformation and national macro-control policies, the load of automobile manufacturing and machining become a new growth point, and the load growth rate slow down compared to the past few years. According to the SZ Plan Report, the maximum load predicted by SZ City will reach 4,150 MW in 2020, and a large number of high-energy-consumption loads will be concentrated and shut down. The impact of load fluctuations on grid voltage are further intensified which form potential threat to the grid operating safely and stably.

Figure 1. Daily load curve of 220kV BQ Station

Figure 2. Curve of 220 kV bus voltage of BQ Station
It can be seen from Figure 1-2 that due to the centralized opening and stopping of the electric arc furnace, the load of the power grid fluctuates greatly in a short time, especially at 8:00, 12:00, 19:00, 22:00. The voltage of the SZ power grid changes drastically. According to the power operation regulations, the daily voltage fluctuation of the 110 kV bus of the 220 kV substation shall not exceed 5 kV. For SZ power grid, the daily voltage fluctuation of the 110 kV bus of the 220 kV substation is close to 5 kV, such as the BQ Substation with high energy consumption and concentrated load. The 3rd and 5th harmonics generated by the centralized operation of the high-energy metallurgical arc furnace are superimposed several times, causing the voltage to be distorted, resulting in the capacitor being more prone to bulk heating, cable breakdown, three-phase voltage imbalance, and capacitor failure rate increasing.

2.2 Overall voltage level is high and some substations lack sufficient voltage regulation measures
Under the typical operating conditions of SZ gird, the main transformer of the BQ Station is operated in the second gear. The 220kV bus voltage is 232kV. When the capacitors are all shut down, the 110 kV bus voltage is between 116~117kV, which is close to the specified upper operating limit (117.7kV). The voltage of the 10 kV bus is between 10.6-10.7kV which has reached the specified upper operating limit (10.7kV). Some substations have been operated to the lowest gear position of the transformer specified in the regulations.

In a particular mode of operation, after the 750kV SH Station was put into operation, the voltage level of 220 kV system in the SZ area was elevated overall. At the moment of the 750 kV SH Station changed its main transformer tap, the voltage of the 220kV bus of the near-field substation has been reduced by 0.52kV ~ 0.77kV, respectively. But the voltage drop of some substation power plants is less than 0.2kV. The voltage of the 220kV bus of the transformer substation is still maintained at about 232kV; the voltage drop of the 110kV bus is 0.06kV~2.42kV, because the tap shift time is just in the period of relatively large load change of the SZ power grid, so the voltage were affected by the load to a large extent, some substation voltage do not drop, but rise.

3. Mathematical model of parallel FACTS with energy storage
Parallel FACTS with energy storage devices consist of energy storage system and converters composition. The converters mostly use a voltage type converter, so it must pass through a power line with the reactor or transformer into the large power system[8]. The structure of this type of arrangement is shown in Figure 3.

![Figure 3. Structure of the parallel FACTS with ESS](image-url)

The mathematical model of parallel FACTS with energy storage depends on the structure and control strategy of the converters. The converters generally use decoupling control of active power and reactive power control. The steady state power output of the device is:

$$P = \frac{U_U \cos(\theta - \delta) - U_i^2 \cos\theta}{\sqrt{R^2 + X^2}}$$

$$Q = \frac{U_U \sin(\theta - \delta) - U_i^2 \sin\theta}{\sqrt{R^2 + X^2}}$$
Take the system voltage $U_S$ as the reference vector, set the voltage $U_i$ as the fundamental amplitude of the output voltage of the converter, and set angle $\delta$ as the phase angle between the converter voltage $U_i$ and the system voltage $U_S$, the connected reactance and the converted impedance of the transformer $Z=R+jX$, impedance angle $\theta = \arctan (X/R)$.

The controller has the outer loop control and inner loop control. The outer loop controller is the main part of the device, its object is the specified power system injection. The specified value of active and reactive power is sent to the inner loop control according to the requirements of the power system. The control object of the inner loop controller is the parallel FACTS device with energy storage, which is responsible for the PWM trigger control of the converter switching element, and calculates the output voltage and phase of the converter according to the active and reactive set values of the outer loop controller. The controller structure of the parallel FACTS with energy storage is shown in Figure 2. In the figure, $U, P, I, \text{and } f$ represent the input voltage, active power, current, and frequency of the outer loop controller of the power system; $P_{\text{set}}$ and $Q_{\text{set}}$ are the power reference value of the outer loop controller to the inner loop controller.

![Figure 4. Control Structure of the parallel FACTS with ESS](image)

The controller of the parallel FACTS with energy storage adopts the phase angle compensation principle to reduce the energy fluctuation between regions by detecting the power fluctuation of the installation location, absorbing the excess electromagnetic power or releasing the insufficient active power of the power system. The controller of the parallel FACTS with energy storage also needs to improve the voltage stability of the power system.

### 4. Simulation case

According to the winter SZ Power Grid in 2018, the parallel FACTS with energy storage device is installed at the 110kV bus of BQ substation. When the impact load starts or exits, it can complete the rapid compensation of power fluctuation and suppress the voltage fluctuation or over-limit phenomenon. By setting the energy storage capacity to 3000MJ, the power fluctuation of the maximum amplitude of 200MW can be suppressed, and the total capacity of the power electronic converter is 200MVA.

Set the impact load in the substation CH station, and add an impact load with a fluctuation of $2.0+j0.8 \ (\text{pu})$ at 1s, lasting for 1s. The software PSASP 7.32 is selected as simulation tool.
As can be seen from Figure 5 and Figure 6, when the device is not installed, the voltage fluctuates dramatically. The fluctuation amount is large and the duration is very long. After the parallel FACTS with energy storage is added, the voltage control level after the disturbance occurs is obviously improved, the fluctuation process is shortened, and it is quickly maintained at a relatively reasonable voltage level. From this case, it can be seen that the voltage fluctuation caused by the impact load has a good inhibitory effect by the parallel FACTS with energy storage.

5. Conclusions

For the problem of excessive voltage and fluctuation of the actual SZ grid, this paper first analyzes the reasons of the voltage over-limit and voltage fluctuation, and points out the lack of voltage adjustment means in the actual operation.

This paper adopts the research idea of the FACTS for the voltage control of power system. The parallel FACTS with energy storage mathematical model is given, and the controller structure of the device are analyzed. By adding parallel FACTS with energy storage to the SZ grid and using the actual operating data to carry out simulation calculations, the calculation results show that the use of parallel FACTS with energy storage has a good inhibitory effect on the voltage fluctuation and voltage over-limit problem, which can be used new reference for the SZ grid planning.

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