Sha-Zhou’s Premier SVC Solution
For wind power integration and transmission capacity boosting

Covering over 6 stations and 12 lines with 2160 KMs of transmission length, the 750 kV second interconnecting Channel from Xinjiang Grid to North West China is one of the largest transmission channels with a staggering 3600 MVA transmission capacity. The major problem of Xinjiang AC power delivery is the feed-in large-scale wind power of Jiuquan wind power base with an installed capacity of 1376 MW. It causes voltage control and reactive equilibrium problem and especially the dynamic reactive compensation caused by wind power active power fluctuation. It also will go worsen as with the completion of Jiuquan 10 GW Wind Power Base during the “Twelfth Five-year Plan” period. The large range and high frequency fluctuation of wind power will cause frequent fluctuation of load flow and voltage on two channels from Xinjiang Grid to North West China Grid through Hexi Grid.

In 2015 during heavy load, the maximum voltage fluctuation of Shazhou Station could reach a maximum of 30 kV. This will be impossible for conventional low voltage reactive compensation devices to meet frequent switching demand. However, a dynamic system with automatic reactive compensation is required to superimpose the problem and it is none other than the SVC.

The current stage of 66 kV SVC dynamic reactive output range allocated for Shazhou 750 kV Substation is ±360 Mvar and SVC dynamic reactive output range allocated for each main transformer in long term is ±480Mvar. It is recommended to use TCR+FC type installation in Shazhou station with capacities of 2 × (TCR: 360Mvar+FC: 3×60Mvar). The configuration’s single unit capacity is the largest SVC device in the world currently.

Compensation Principle

a. Transmission line mostly uses reactive load compensation for balancing reactive power loss. During transmitting active power, it adjusts 750kV line side voltage to make it within reasonable tolerance i.e. 750kV~800kV. One of the major concerns is
the requirement of large charging power for 750kV transmission line. To do this, it requires a large no-load terminal voltage. Hence the reactive compensation allocation should be able to meet the requirement of switching no load line and also ensure voltage on both sides of line in between 750~800kV.

b. Furthermore, the grouping capacity of reactive-load compensation equipment shall meet voltage fluctuation requirement. In addition, the voltage fluctuation at medium voltage side during switching shall not exceed 2.5% of rated voltage.

c. The adjustment of transformer tap position along with reactive-load compensation ensures a controlled node voltage.

The allowable scope is:
- 750kV operating voltage is controlled within 750kV~800kV.
- 230kV system busbar voltage is controlled within 330kV~363kV.
- 220kV system busbar voltage is controlled within 220kV~242kV.
- 750kV main transformer tertiary winding voltage is controlled below 73kV.
- The allocation of reactive-load compensation equipment shall be made by combining with transformer tap position

System Allocation

The project connects the SVC to a 66kV bus bar with a compensation capacity of -360 Mvar~360 Mvar. The SVC equipment includes:
- Two TCR branches with rated capacity of 360Mvar
- Two FC3 branches with rated capacity of 60Mvar
- Two FC5 branches with rated capacity of 60Mvar
- Two FC7 branches with rated capacity of 60Mvar

Project Innovation

(1) Increase in voltage level and SVC capacity, steeply rises the heat flow of valves. Hence, the implementation of our patent technology with double parallel branch waterway cooling system is introduced to significantly increase the heat emission efficiency of valve group.
(2) We have put forward SVC magnetic clearance requirement in Shazhou station to safe levels. Therefore increased space magnetic field distribution will have no effect for site equipment installations.

(3) Our all new star frame structure, a patented technology is used for reinforcing the structural strength of TCR as well as limits the eddy-current loss and lowers temperature rise. Hence ensures its long-term safe operation.

(4) The project uses high speed optic fiber data network to connect two sets of SVC of Shazhou Station. Hence ensures coordinated and balanced reactive output between two SVCs.

**Technical Analysis**

1) **Equipment parameters:**

General Parameters:
- Rated voltage: 66kV
- Rated capacity: 360Mvar
- Rated firing angle: 105°C

Thyristor parameters:
- Non-repetitive peak voltage $V_{DSM}/V_{RSM}$: 6500V
- Repetitive peak voltage $V_{DRM}/V_{RRM}$: 5600V
- Average on-state current $I_{AVM}$: 2810A
- Threshold voltage $V_{T0}$: 1.12V
- Slope resistance $r_T$: 0.290m
- Reverse recovery charge $Q_{rr}$: 2700~3700μAs

Each phase of Shazhou SVC Project consists of two groups of valves in series. Each group of valve has 20 levels of thyristor and each single level is composed of a pair of anti-parallel thyristors, including auxiliary circuit (trigger, protection, voltage-sharing, damping element, etc.).

2) **Valve characteristics:**

a. **Vertical press stack valve structure**
   - Use vertical press assembly technology
   - Small volume, light weight, comprehensive transportation to reduce cost
   - Quick installation, simple and compact structure, easy maintenance to increase reliability and decrease off time

b. **Advanced electro-optical triggering**
   - Simple structure, small volume and light weight
   - Directly receives energy from primary circuit
   - Control through optical cable
   - Integrated thyristor over-voltage protection function

c. **Thyristor over-voltage protection**
   - Traditional method accepts BOD component to protect the thyristors from over voltage. Nevertheless, increase in withstand voltage and BOD dimension makes it impossible to implement. In addition to that, with increase in BOD components, the break-over voltage deviates more.
   - However special function electronic circuit ensures low break-over voltage deviation and realizes over-voltage protection of thyristor with greater accuracy.

d. **Patented cooling system**
   - The industrial grade sealed pure water cooling method with deionization function ensures high reliability and greater operation of SVCs. The technology is widely used in locomotives, aviation, multi MW generators, UHVDC etc.
Control Strategy

To reduce the influence of large-scale fluctuation of wind power and to control 750kV bus bar voltage within allowable range, the project introduces various functions by the SVC. Such as:
1. SVC will control the steady-state wave motion of 750kV bus bar voltage by controlling the reactive output capacity.
2. If any system disturbance caused by fault or load shedding appears, SVC will inhibit transient state fluctuation of 750kV bus bar by controlling its reactive output to make bus bar voltage return to normal state.

UAPC Platform

The project integrated itself with our patented control & protection technology, a technology based on the UAPC (Unified Advanced Platform for Protection and Control) platform. The high performance decentralized and distributed system with friendly man-machine environment, makes it more convenient for function extension. This platform adopts multiple CPU and DSP in series for coordinated operation, to fasten the system response speed & accuracy. Meanwhile it also meets the demand for rapid responding of SVC to adjustment in a proper way.

UAPC platform includes hardware, software and visual development tool and constitute a complete solution for control system.

This platform uses advanced CPU, DSP and FPGA to realize high performance data processing. Increased arithmetic capability, processing ability and synchronized parallel working with improved processing makes it more favorable for multiple media works. Not limiting to above, it has also a highly reliable internal synchronous bus bar technology (HTM bus), which ensures the reliability of transfer data between media boards. This supports distributed computing and balancing of load to enhance the system performance.

SVC Performance

- For a single set of SVC, an addition of 3.2 % higher value from 180 Mvar is provided for all three filters at rated voltage of 66kV.
- Maximum inductive reactive output of single set of TCR is about 405~406Mvar, about 12.5~12.8% higher comparing with designed 360 Mvar capacity.
- Maximum reactive adjusting range for single set of SVC is -186Mvar (capacitive) ~219Mvar (inductive), 12.5~12.8% higher comparing with corresponding 360Mvar of designed -180Mvar (capacitive) ~180Mvar (inductive).
■ Total maximum reactive adjusting range for all two sets of SVC is -371.2Mvar (capacitive) ~439.7Mvar (inductive), and adjustable reactive span of 844.6Mvar, 17.3% higher comparing with corresponding 720Mvar of designed -360Mvar (capacitive) ~360Mvar (inductive).

■ The step response time of SVC is about 48.8 ms which is well under stipulated agreement.

■ During the live switching of TCR and filter for 3rd, 5th and 7th, the maximum measured overvoltage at site is 75kV, far lower than rated insulation level of low resistance.

Project Benefits

■ Under large operation mode, the voltage capability of SVC in Shazhou Substation for 750kV bus bar is 3.1% (-1.55%~1.55%), for 330kV bus bar is 9.1% (-4.55%~4.55%) and for 66kV bus bar is 22.4% (-11.2%~11.2%);

■ Under small operation mode, the voltage capability of SVC in Shazhou Substation for 750kV bus bar is 5.4% (-2.7%~2.7%), for 330kV bus bar is 11.1% (-5.55%~5.55%), and for 66kV bus bar is 24.6% (-12.3%~12.3%).

■ As one of the restrictive condition of SVC output, 66kV bus bar voltage can effectively avoid the influence of voltage fluctuation on relevant substation.

■ Implementation of SVC lowers the voltage fluctuation range of Shazhou substation from 25.6kV to 5.6kV during 1000 MW wind power fluctuation.

■ SVC plays an important role for boosting the voltage and improving power capacity of 800 MW for Kumul-Zhengzhou HVDC single-pole after fault.

■ During three-phase permanent fault in Hexi-Jiuquan single-circuit line, our SVC stands as the savior and improves up to 200 MW power.

■ The operation of SVC at Shazhou sub-station has reduced the generator tripping and generator tripping power by 500~1000 MW.