Summary on Reactive Power Compensation Technology and Application

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Abstract—**This paper, firstly, pointed out the reactive power compensation concepts, principles and importance for safe and economic operation of the grid. It had a detailed description of the technical principles of several major reactive power compensation devices and illustrated the application of reactive power compensation on harmonic suppression, wind farm, mines, electric railway and other aspects.**

Keywords-reactive power compensation; SVC; STATCOM; harmonic; wind farm; mines; electric railway

I. INTRODUCTION

Transformers, asynchronous motors and other inductive loads will absorb reactive power from the grid during their operation periods, which, to a certain extent, will reduce the system power factor. The reactive power demand can be compensated by reactive power compensation device, which is helpful to reduce the reactive power flow in the grid, reduce the electric energy loss due to the delivery of reactive power, and in turn, improve the operating condition of the grid. This phenomenon is called reactive power compensation [1-2].

The basic principle of reactive power compensation consists of three parts: stratified by voltage, partition by the power grid and local equilibrium. In the power system, reactive power should be maintained balanced, or otherwise, it would worsen the system voltage, and even cause the voltage collapse accidents. In addition, if the voltage is lower, it will reduce equipment utilization and increase the line loss. Therefore, the optimization and compensation of the grid system have great significance to improving the voltage quality, power factor and the efficiency of the power supply. It is also useful to reduce the system losses. It is a foremost energy saving technical measure with small investment and quick returns [3].

II. THE TECHNICAL PRINCIPLES OF THE REACTIVE POWER COMPENSATION EQUIPMENT

A. SVC

SVC is a reactive power compensation device, which has the major forms of Thyristor Controlled Reactor (TCR), Thyristor Switch Capacitor (TSC), the mixing device of TCR and TSC, etc. Its operation mechanism is power electronics technology. SVC is a widely used dynamic reactive power compensation technology device at the moment, which is due to the ability to solve the problem of three imbalances, low power factor, high harmonic content, the voltage fluctuation and flicker [4]. SVC has occupied a dominant position among the type of stationary reactive power compensation device in some economically developed areas [3]. Its principle is shown in in Figure 1.
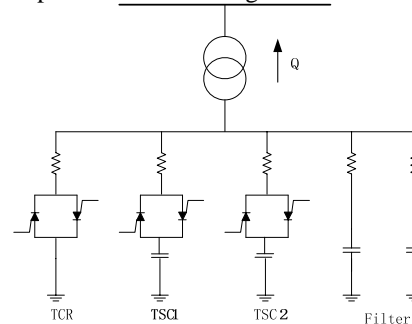

Figure 1. Schematic diagram of working principle of SVC

Firstly, SVC can be used as system compensation device to maintain the transmission line capacity, to improve transient stability of the power grid, to improve the transmission capacity of active power and static stability of the grid, to increase the system damping and restrain the power oscillation. Secondly, it is also can be used as a load compensation device to suppress voltage fluctuation and flicker caused by load changes, to improve the power factor and optimize energy flow within the network, to compensate for active and reactive power load imbalance.

However, there are some shortcomings in the application of SVC. It belongs to impedance compensators. With the voltage dropping, the reactive power output drops by the relation of square to the voltage. When the voltage is low, that process will get into a vicious cycle. And as its main element, IGBT converter itself has certain uncontrollable nature, which is accompanied by the harmonic.

B. STATCOM

With the application of high-power and full-controlled power electronic devices, such as GTO, IGBT and other various controlled techniques (PWM, phase control technology, four-quadrant converter technology), the development of the inverter technology accelerates. On this basis, a new stationary reactive power compensation technology (ASVG) – STATCOM becomes a hot point in the field of reactive power control research [5].

STATCOM, as a member of the FACTS family, is important shunt compensation equipment. It can be divided into two types by its circuit, one is voltage-bridge circuit

(shown in Figure 2), the other is current type bridge circuit (shown in Figure 3).
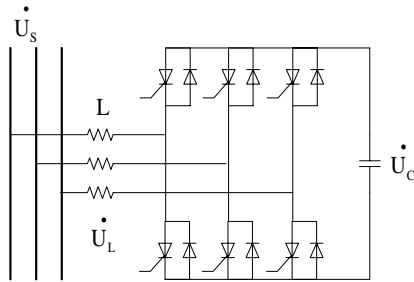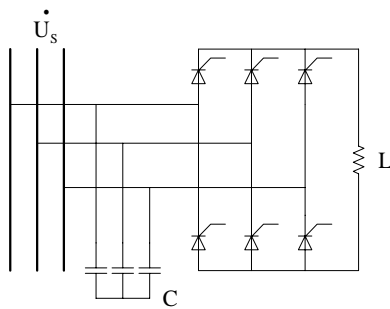

Figure 2.   Voltage type bridge circuit

Figure 3.   Current type bridge circuit

In the following, the voltage-bridge circuit is taken as an example to illustrate the basic operating principle of STATCOM.

Capacitor is connected to the power line in parallel with the bridge circuit, which can adjust the output voltage by adjusting the commutation angle of the shutting down device. Thus, the reactive power can be provided in a real-time and dynamic way.

There are two main directions for STATCOM to better the power quality: one is improving the power factor, the other is improve the power grid voltage [6].

1) Improve the power factor.

The simplified wiring diagram of STATCOM system is shown in Figure 4. E_s stands for the equivalent potential of the infinite system. R_s+jX_s is the equivalent Thevenin impedance from the load side. $R_{eq}+jX_{eq}$ stands for the equivalent impedance of STATCOM. U is the voltage at the point of junction between the STATCOM and system, which is namely the voltage of the common connection point. When the STATCOM is in the standby state, the system undertakes all the reactive component (I_{LQ}) of the load current (I_L), and I_{SQ} is equal to I_{LQ}. If the I_{LQ} is larger, the load power factor will be reduced and the line loss will be increased. When the STATCOM is put into operation, the capacitive current I_{CQ} will moderately compensate reactive

component I_{LQ} of the load current, which will reduce the reactive power demand. In the ideal case, I_{CQ} is equal to I_{LQ}, load reactive current will be neutralized completely by the STATCOM, Which will achieve the best condition with the power factor of 1.
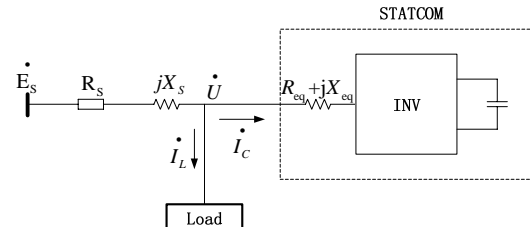

Figure 4.   System wiring diagram of STATCOM

2) Improve the power grid voltage.

The voltage of the amplitude nodes in the network is determined by the reactive power demand. Once reactive power demand of the system exceeds the maximum reactive power, it will produce large amounts of reactive power flowing in the network, which is bound to worsen voltage and increase the net loss. Assuming that the active component and reactive component providing by the system in Figure 4 are P_S and Q_S, the active and reactive power demand needing by the load are P_L and Q_L, the reactive power providing by the STATCOM is Q_C. Then when STATCOM is not put into operation, the system will supply for the reactive power load demand, and Q_S is equal to Q_L. The voltage loss system can be expressed as follows:

$$\Delta U = \frac{P_S R_S + Q_S X_S}{U} = \frac{P_L R_S + Q_L X_S}{U} \quad (1)$$

When the STATCOM is put into operation, it can appropriately compensate reactive power load demand, there is:

$$Q_S = Q_L - Q_C \quad (2)$$

At this point, the system voltage loss is listed as follows:

$$\Delta U = \frac{P_S R_S + Q_S X_S}{U} = \frac{P_L R_S + \left(Q_L - Q_C \right) X_S}{U} \quad (3)$$

By the formula (1) and (3) showing that, as long as there is proper control of the STATCOM reactive power output Q_C, the system voltage loss will be reduced, in turn, the voltage level of the whole system will be adjusted and the voltage quality, voltage passing rates and other indicators will be improved.

C. SSSC

Static Synchronous Series Compensator (SSSC) is a static synchronous series compensator device based on voltage source inverter. SSSC serves as series compensated device for transmission lines, whose compensated voltage is $90°$ different from the current in series and can be controlled [7] in a range of capacitive to inductive.

The system architecture of SSSC is shown in Figure 5, including a voltage converter, coupling transformer, DC link and control system. The coupling transformer is in series with the transmission line and the DC link are generally capacitors, DC power or energy storage device [8].
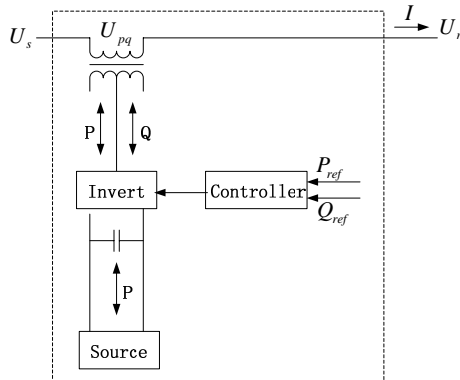
Figure 5.   System structure diagram of SSSC

III. APPLICATION OF REACTIVE POWER COMPENSATION TECHNOLOGY

A. Harmonic Suppression

Reactive power compensation should be consist of the compensation for both the fundamental wave reactive power and the harmonic reactive power. The compensation shown above is fundamental wave reactive power. When it comes to the harmonic reactive power, the harmonic suppression should be taken into consideration [7]. Currently, the most widely used power system harmonic suppression method is combining the active filter and the passive filter [9-10], that is, hybrid active filter. Paper [11] and [12] described a mixed type of hybrid active filter (HAPF), which can make use of not only the excellent performances of APF but also the low cost of PF. In this filter, the passive parts to compensate reactive power shortfall and the active parts to aid improve the overall filtering characteristics of passive filters, to overcome the shortcomings of the susceptibility of the passive filter and so on. Paper [13] proposed a design method of the new series hybrid active filter. The system consists of a parallel resonant passive filters and series active filter based on the fundamental magnetic flux compensation. The new series hybrid active harmonic filter can efficiently handle a variety of harmonic sources and prevent the over-current phenomenon of the passive portion.

B. Wind Farm

Grid connected operation of the wind farm has a wide range of effects, such as: intermittent of the wind can cause fluctuation of the output power, when the wind farm reactive power compensation is insufficient, the voltage of the access point will also fluctuate and even cause "voltage flicker". As a result, the grid voltage and the stability of the grid will be affected. In addition, when the operation of the grid is in failure, it is required to keep rapid parallel operation of wind farms and provide modest shortfall of reactive compensation to help the auxiliary system voltage return to normal, that is, the wind farm must have the upward crossing function in the low pressure state. All of these require the wind farms to have a considerable reactive power compensation performance.

The slow switching and discrete amount of compensation and other shortcomings of the capacitor bank limit its application in wind farm. Some experts and scholars had proposed studies that mixed MCR, SVG and STATCOM to compensate reactive power of wind farm [14-15]. Paper [14] proposed the application of the STATCOM to wind farms, and in line with the original wind farm reactive power compensation case, and wind farms in improving stability and low voltage ride through capabilities, while reducing the investment in continuous compensation equipment. The structure is shown in Figure 6.
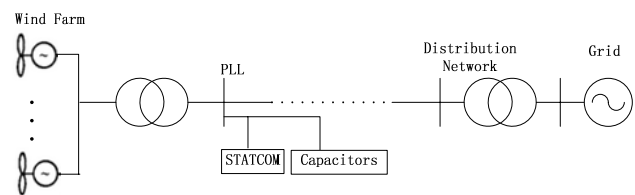
Figure 6.   The structure of the wind farm with hybrid compensation of STATCOM and capacitor

Reactive power compensation device consists of a STATCOM and multiple sets of switching capacitors. The capacity of STATCOM is the same with a single set of capacitor. The capacitor bank is responsible for the compensation for base portion of reactive power required by the wind farm to achieve "rough up"; the STATCOM is responsible for the compensation for fluctuation reactive power that caused by the capacitor switching within the threshold to achieve "fine fill "[8].

C. Mine

Hoist is one of the widely used production equipment in mining enterprises, with the characteristic of high-power and high energy consumption. Mine hoist system widely uses rectifier device consisting of power electronic devices to power and control its DC motors. Frequently start and stop in the mining process are needed by hoist in mining, which has severe impact on safety and stability of the power supply system by reactive power and harmonic pollution, resulting in high failure rate and short life of the electrical equipment. Low power factor leading to underutilization of energy and a lot of power is wasted. Therefore, the study of the

appropriate reactive power compensation and harmonic suppression technology according to the characteristics of mine hoist is of great significance to improving the quality of power supply, to ensuring mine safety, stable and to efficient production.

Paper [15] proposed the method of combining the thyristor controlled reactor TCR and fixed capacitors FC for reactive power compensation and harmonic governance, according to the characteristic of the reactive power, power factor and harmonic. Comprehensive consideration of the features of the system and the reality of the reactive power compensation, the SVC will be installed on the 6kV bus, where the hoist is installed. FC filter branch mainly are 11th and 13th, according to the filtering characteristic. The SVC is mainly composed of the TCR, FC, protecting system and control device. At the same time, the use of delta connected TCR branch is to prevent the potential third harmonic by compensation means. And the specific structure is shown in Figure 7.
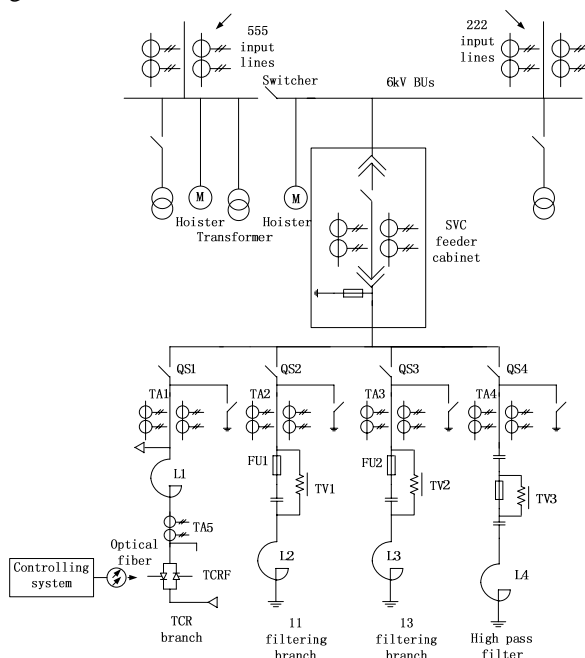

Figure 7.   System circuit structure diagram of SVC device

Paper [16] designed a reactive power compensation and harmonic governance program, in which the Static Var Generator SVG is combined with fixed filter group FC.

D.   Electrial Railway

Electric locomotive is a high-power single-phase rectifier load, which causes the traction load of the electric railway exhibits shock resistance, asymmetric and non-linear characteristics [17]. The harmonics, three-phase voltage and current imbalance will occur in that situation, resulting in voltage and current distortion, three phase imbalance and other abnormal indicators. All those problems will directly restrict the economy, influence stability and safe operation,

as well as electrical safety of millions of users of the electricity network.

To improve the power factor of the electrified railway power supply system, the mainly used mature reactive compensation devices for electrified railway in China are listed as follows [18,19]: fixed capacitance compensation, mechanically switching capacitor compensation (MSC), thyristor controlled reactor (TCR) together with fixed compensation filter, magnetic valve controllable reactor compensation (MVCR) combined with fixed filter compensation. Paper [22] made comparison and study a variety of reactive power compensation scheme of electrified railway on the basis of detailed analysis of electrified railway traction power supply system. It analyzed and summarized the advantages and disadvantages of the various programs and promoted Chinese electrified railway construction.

In addition, the reactive power compensation is tried to be used in the energy-saving in grids [20], substations [21], the chemical industry [22], oilfield [23] and so on, which makes quite good social and economic benefits.

IV.   CONCLUSION

Reactive power compensation device, SVC, STATCOM and SSSC, is widely used in transmission and distribution network, large industrial mining, electric railways, wind farms and other occasions, which plays a key role in suppressing flicker, reducing losses, voltage supporting and so on.

With the implement of the energy saving policy thoroughly and the improvement of the grid reliability requirements, the dynamic reactive compensation technology will be more promoted and applied. Its compensation way will vary with the system changes and ultimately boost further reactive compensation technology integration and development.

REFERENCES

[1]   Wen Zengyin, HeYangzan. Electrical System Analysis, Huazhong University of Science and Technology press [M]. Published in 2002.

[2]   Jin Lijun, An Shichao, LIAO Liming, et. al. Present Situation and Development of Reactive Power Compensation Both at Home and Abroad [J]. Voltage Apparatus, 2008, 05:463-465.

[3]   Dong Yunlong, Wu Jie, WANG Nianchun, et. al. Summary on Reactive Power Compensation Technology. Energy Conservation [J], 2003, 09:13-15+19-2.

[4]   Chen Jun, Wen Fuguo. Performance and Application of Static var Compensation [J]. East China Electric Power, 2009, 05:797-799.

[5]   Deng Jiaze, Wang Ben,HUANG Chongxin,et.al. Reactive Power Compensation Control Based on Thyristor Based STATCOM [J]. Power System Technology, 2009, 01:48-51.

[6]   Rong Fang. Discussion on the Dynamic Reactive Power Compensation Technology of Distribution Network [J]. Electrical technical Application,2009,13: 72-75

[7]   Wang Zhaoan, Yangjun. et.al. Harmonic suppression and reactive power compensation [M]. Machinery Industry Press. Published in 2013.

[8]   Li Hongzhong, JinYixiong. et.al. Reactive power compensation and voltage reactive power control in regional power network [M]. Machinery Industry Press. Published in 2012

[9]   Kang Mingcai, Yang Zhiqiang. Improvement on the Power Factor of Non-sinusoidal Circuit [J]. Journal of ShanXi Science School, 2007,

23(3):20-25.

[10] Niu Rongjian, Zhang Xiaoqin. The Harmonic Problem in the Power System [J]. Journal of ChongQing Technology School, 2006, 8(3):87-89.

[11] Jiang Qirong, Zhao Dongyuan, Chen Jianye. Active power filter-structure, principle, control [M].Beijing: Science Press, 2005.

[12] Kou Lei, Luo An, CHU Qiang. A Novel Series Hybrid Active Power Filter Capable of Suppressing Various Types of Harmonics [J].Power System Technology, 2013, 07:2024-2029.

[13] Liu Chongyang, Song Lei. An Applied Research of Hybrid Reactive Power Compensation System in Wind Farm Grid [J]. Electrical Automation, 2013, 03:63-65+83.

[14] Yang Fu. Study on the application of STATCOM in wind farm reactive power compensation [D].Shandong University, 2012.

[15] Yang Saiqiang. Application of TCR+FC reactive power compensation technology in the mine hoisting system [D]. Zhongnan University, 2013.

[16] Xiao Jin. Research and application of SVG+FC reactive power compensation and harmonic control technology for mine hoist system [D]. Zhongnan University, 2014.

[17] Xiao Xiangning. Power quality analysis and control, China Electric Power Press [M]. Published in 2004.

[18] Xiao Zhenghu. Research on reactive power compensation method for electric railway load [D]. Xi'an University of Technology, 2010.

[19] Xiao Jingshuai. WEI Ling. Analysis of Strategy about Var Compensation for Traction Power Supply Systems of Electrified Railway [J]. Journal of Liaoning University of Technology (Natural Science Edition), 2011, 03:153-155+167.

[20] Huang Yi. Research on comprehensive planning of distribution network energy saving in Foshan City [D].South China University of Technology, 2013.

[21] Di Xiaoyuan. The Energy Saving of the Reactive Compensation in the Electric Power Substation [J]. Journal of Hubei Water Resources Technical College, 2007, 03:47-50.

[22] Wang Yunjuan, Jiang Guangjin. Energy-saving reformation of reactive compensation for chemical enterprise [J]. Electric Drive Automation, 2009, 01:61.

[23] Zhu Yifei. The Use of Dynamic Reactive Power Compensation Technique to Achieve Energy-saving of Shengli Oilfield[J].Power Demand Side Management, 2009, 02:42-44.