Review of Modern Reactive Power Compensation Technology

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Abstract. With rapid development of economy, the importance of electronic engineering is improving gradually. As a significant way to improve stability of power grid and quality of electric energy, modern reactive power compensation technology is an indispensable part in our daily life now. First of all, research background and significance of modern reactive power compensation technology were introduced in this paper, followed by an analysis of the meaning of reactive power compensation, emphatically introduces the current research status, and some of the key technology of the reactive power compensation are analyzed. At last, its application in motor and research trends are introduced.

Introduction

Over the past 30 years, we get more and more inductive load in power grid with the rapid development of power electronics technology. Due to the extensive use of inductive load, not only makes lots of reactive power flow in the power grid and a grate line lost, but also affects the power quality and voltage stability.[1,2] The birth of the power system, generates reactive power compensation technology, and with the improvement of complexity of power system, the corresponding technology of reactive power compensation is in constant increase. The reactive power compensation device have become to SVC, STATCOM and a variety of FACTS devices from parallel capacitor, synchronous condenser at the beginning. The traditional reactive compensation technology is simple, it is to parallel reactive power compensation device such as parallel capacitor to the bus, and modern reactive power compensation technique is to use more advanced control strategies, or more advanced intelligent algorithm to control the reactive power compensation device, realize the dynamic reactive power compensation, increase the positive damping of power system. Major role of modern reactive power compensation technology is energy conservation and loss reduction, improve power quality and system stability.

There is a lot of people think that the reactive power compensation is to improve the power factor of user side, this view is very one-sided, the role of reactive power compensation technology is not limited to this, more important is that it can provide voltage support for the whole power system, and effectively prevent the voltage from fluctuation, flicker, bifurcation or even collapse.[3,4] The reactive power compensation have taken an important role in improving stability of system and voltage stability especially, so it is crucial to develop reactive power compensation technology and this is a matter of great concern.

Definition

Reactive power is a kind of power which is used to establish and maintain the magnetic field in electrical equipment, complete the conversion of electromagnetic energy, but it does not do any work, it can only make the exchange of energy between electric field and magnetic field so that the active power can be transported from power supply to load, this is one of the biggest characteristics
of reactive power. At present, the definition of reactive power is the traditional one. This definition is based on the premise which is the single-phase or three-phase symmetrical sinusoidal steady circuit. When there is harmonic or unstable load in the power grid, it will not current. At present, there is no completely suitable definition of reactive power for the situation of having asymmetric three-phase load or non sinusoidal occasion in the world now, but there is a certain research foundation: in 1920s, Budeanu proposed the definition of reactive power in frequency domain. And in 1930s, the definition of reactive power in time domain is put forward by Fryze. With time passing by, new reactive power definitions and theories are constantly updated, but they all can not solve the problem completely. At present, the definition of reactive power is difficult, because its definition must meet three conditions at the same time. Its requirements are shown in Table 1.

Table 1. Requirement for the Definition of Reactive Power.

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<td>1</td>
<td>have accurate physical meaning, can explain all kinds of power problems</td>
</tr>
<tr>
<td>2</td>
<td>can distinguish the concept of reactive power and harmonic source clearly</td>
</tr>
<tr>
<td>3</td>
<td>easy to measure</td>
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</table>

As for a system having a standard sinusoidal voltage source and linear load (resistor-inductance load), its voltage and current is: 

\[ u(t) = \sqrt{2} U \sin(\omega t) \quad i(t) = \sqrt{2} I \sin(\omega t - \phi) \]

In the formula, \( U \) and \( I \) are the effective value of voltage and current, \( \omega \) is the angular frequency of the system, so the instantaneous power in this system is:

\[
p(t) = u(t)i(t) = 2UI \sin(\omega t) \sin(\omega t - \phi)
\]

\[
= UI \cos \phi [1 - \cos(2\omega t)] - UI \sin \phi \sin(2\omega t)
\]

\[
= 2UI \left[ -\frac{\cos(\omega t + \omega t - \phi) - \cos(\omega t - \omega t + \phi)}{2} \right]
\]

\[
= UI \cos \phi - UI \cos(2\omega t - \phi)
\]

Traditionally, the reactive power is always defined without mathematical meaning as:

\[ Q = UI \sin \phi \]

The active power can be understood as the average value of the instantaneous power in a period, and the reactive power can be interpreted as the maximum value of the exchange power between the power supply and load.

So, there is another way to express \( p(t) \):

\[
p(t) = P[1 - \cos(2\omega t)] - Q \sin(2\omega t)
\]

And the condition of this system can shown as schematic diagram in Fig.1 using formula (2). A part of power (area in green) is back to the power supply and another part of power is to load from power supply (area in blue) in one period, this feature is also shown in the formula (2). In other words, its mathematical implications and physical implications are in good combination and match with each other, so this traditional method of definition in single-phase system is very maturational now, so the definition on three-phase non-sinusoidal system causes people’s attention gradually.
In recent years, the most representative definition of reactive power is the instantaneous reactive power theory by Japanese scholar H. Akagi, proposed in 1983. This definition breaks through the traditional definition of power which based on the average value, it proposed instantaneous active power, instantaneous reactive power innovatively, create a good solution of the detection of instantaneous value of reactive power, promote the research and rapid development of reactive power compensation device greatly. But this definition have barely no physical sense, and it is not the effective identification of harmonic and reactive power, it also have barely no contact with traditional definition of reactive power. This is the biggest problem in this definition currently.[5]

A major theoretical problem of reactive power compensation technology is the accurate definition of reactive power. At present, there is no perfect definition of reactive power in the world, if we want to realize the wide range extension of reactive power compensation technology, the definition of reactive power is one of the most difficult problems that we should get it done well.

Research Status

The Current Situation of The Development of Reactive Power Compensation Device

The reactive power compensation device is the cornerstone of reactive power compensation technology, and it provide a grate help to the development of reactive power compensation technology, to a large extent.

In 1970s, the development of power electronics technology has made the transition from the traditional reactive power compensation technology to the modern reactive power compensation technology, the sign of change is there has a variety of advanced reactive power compensation devices shows up. Here is a brief introduction about two representative of the modern reactive power compensation device.

Static Var Compensator(SVC). The first generation of SVC showed up in 1967, and it is saturated reactor (SR). Under the impetus of the power electronic technology, the SVC that using thyristor have put into use officially In 978. At present, there have already a variety of SVC, such as thyristor controlled reactor (TCR), thyristor switched capacitor (TSC) etc. And it is the most widely used reactive power compensation device in China. Here are some compare among different kinds of SVC that in common use, they are shown in tab 2.

<table>
<thead>
<tr>
<th>Responding speed</th>
<th>SR</th>
<th>TCR</th>
<th>TSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorb reactive power</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Classification</td>
</tr>
<tr>
<td>Harmonic</td>
<td>Big</td>
<td>Big</td>
<td>None</td>
</tr>
<tr>
<td>Loss</td>
<td>Big</td>
<td>Small</td>
<td>Small</td>
</tr>
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STATic COMpensator (STATCOM). STATCOM appeared in 1980s which based on converter technology. STATCOM can be regarded as a constant voltage source, it uses full-controlled devices such as IGBT, GTO etc. And it can control the amplitude and phase of output voltage, provide dynamic voltage support. Compared with SVC, STATCOM has stronger ability of reactive power regulation, more flexible application range and higher ability to maintain voltage stability. STATCOM is a research hotspot, because it represents the development direction of reactive power compensation device: not only can compensate reactive power but also suppress the harmonic. And STATCOM is the most important device in flexible AC transmission system (FACTS).

At present, the research point about STATCOM has divided into two directions: one is develop its control strategy, another is develop the unified power flow controller (UPFC), and they both have good research result now.

Key Technology

Modern reactive power compensation device is the cornerstone of reactive power compensation technology, but its core is the control strategy. And the current development bottleneck is how to properly use control strategy to solve the problem of voltage stability.

Here are some key technology:

**Determination of the Capacity of Reactive Power Compensation and the Installation Location of the Device.** There is a intimate relationship between the capacity of reactive power compensation and the installation location of the device, and according to the different installation position, there have different capacity determination method. The appropriate installation site will get the flow reactive power in line reduced, reduce line losses, and improve the power factor of electric equipment. The present problem is how to correctly choose the switching capacitor capacity to realize the stepless switching, and how to find the optimal compensation point with considering other control variables and network loss increment rate.

**Harmonic Treatment Technology.** Because of the close relationship between reactive power and harmonics, harmonics is a big problem remain to be solved in reactive power compensation, the traditional reactive power compensation technology will bring harmonic, so the modern reactive power compensation technology must solve the harmonic problem.

At present, in the field of reactive power compensation, the filter system is mainly depended on the devices with filtering function (such as STATCOM) to treat harmonics. And the problem of treating harmonics is how to realize the integration of reactive power compensation and harmonic management.

**The Secondary Voltage Control Technology.** This technology was put forward by Electricite De France (EDF) in 1978. In this scheme, the power grid is divided into areas that are decoupled from each other, by controlling the reactive power absorbed or emitted by the unit to control the voltage of the dominant node in a certain region. But the scheme rely heavily on strict zoning, so it is not suitable for system which having intimate coupling. In recent years the coordinated secondary voltage control technology has been basically solved this problem, at present the biggest problem is how to deal with the interaction of regional flow.

**Tertiary Voltage Control Technology.** This technology is a method that evolved from the secondary voltage control technology gradually, like Fig.2 shows. Now it has widely used in western developed countries. And this technology is a more advanced voltage control mode, cause it can effectively prevent the voltage from flicker or drop. At present, the problem needs to be done is how to consider the reactive power flow, support and how to control the region reactive power flow among different areas.
**Economic Pressure Difference Computing Technology of Reactive Power Flow.** If reactive power equinox of transmission line just locate in the line midpoint, the line voltage difference between the two ends of the line at this time is called economic pressure difference. Each line has a reactive power equinox, and it located in the midpoint of the line, this flow is called economic voltage difference without power flow.

The technology is unique in China, it serves to the second generation of automatic voltage control (AVC) technique. In this algorithm, the operation parameters of the power grid are introduced into the calculation, which is simplified and assuming these variables are continuous and adjustable. But this way is essentially a local optimization, and the optimization accuracy may not be guaranteed.[15]

**FACTS Technology.** FACTS can control reactive power, voltage, impedance and phase angle in the power system, so as to improve the security and stability of power system[16]. Now, the FACTS mainly aims at improving the static and transient stability of the system, and now the main problem is how to get the installation location, parameters setting, harmonic suppression and control strategies cooperated to realize the optimal power flow control.

**Intelligent Algorithm**

We usually get a complex mathematical model when we calculate the optimal solution toward a variable in power system, it is difficult to establish accurate mathematical model, because there are not only transcendental function, but also a large number of variables, which extremely easy to cause the "dimension disaster", bring a great amount of computation. When we deal with these problems, the effect of the traditional algorithm is not ideal, so we generally use intelligent algorithms to solve this problem.

The intelligent algorithms is used to get the intelligent algorithms by simulating natural processes, using the principle of bionics, there are a variety of intelligent algorithms now, such as simulated annealing algorithm, genetic algorithm, tabu search algorithm, ant colony algorithm, particle swarm optimization algorithm, neural network algorithm and so on. The application of intelligent algorithm can greatly simplify control strategy, reduce the amount of computation.

But with the complexity of the power system increasing and expansion of the scale, the intelligent algorithm also cannot ensures to reduce the calculated amount, because the solving speed and global optimal solution is a pair of contradictory variables in nature, we cannot get them both, and in general intelligent algorithm, it will not go for search when it have found a local optimal solution, so it is very easy to fall into the local optimal solution.

Now, we usually select the corresponding intelligent algorithm according to the characteristics of the problem. In the future research of intelligent algorithm, there will have more and more intelligent algorithms get updated, or update the version of the algorithm which combining the two intelligent algorithms, and there are certain research results already.
Summary

The reactive power compensation device is the cornerstone of the reactive power compensation technology, in recent decades, due to the drive of the power electronic technology, there has been a rapid development of reactive compensation technology, even have beyond the corresponding control strategy development, showing a serious advance, resulting in although the reactive power compensation device is advanced, full-featured, but there is a lack of its good control strategy seriously.

Overall, the modern reactive compensation technology should focus on the improvement of control strategy in the future, not seize the compensation device development hardly. Such as FACTS technology, at present, the reactive power compensation device is already fairly advanced, the biggest bottleneck in the development is the lack of good control strategy. With better control strategy, the devices can be in more complex environment and show better performance characteristics, control strategy is the core of reactive power compensation technology after all. In addition, in order to simplify control strategy, the intelligent algorithm should be updated or improved, as much as possible to achieve the ideal state: not only can get the global optimal solution, but also can ensure the solving speed.

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