Concept of Reactive Power and Voltage Stability in Power System Network - A Review

Namrata R. Thakur
Electrical (Electronics & power), SGBU/DES's COET, Dhamangaon Rly, Maharashtra, India.

Tushar T. Balpande
Electrical (Electronics & power), SGBU/DES's COET, Dhamangaon Rly, Maharashtra, India.

Kishor Deshmukh
Electrical (Electronics & power), SGBU/DES's COET, Dhamangaon Rly, Maharashtra, India.

Abhishek Thaknaik
Electrical (Electronics & power), SGBU/DES's COET, Dhamangaon Rly, Maharashtra, India.

Abstract – In recent days it has been necessary to understand the concept of reactive power and its effect on the electrical power system. Also the need of voltage stability is studied. The important of this topic is basically to understand the reactive power concept and voltage stability methods used in the power system network. Some challenges in the research area had different issues which are solved with the help of voltage stability concept. Electric utilities are facing the voltage stability challenges mostly, so it is an economical solution to overcome this challenge. It began with an overview of reactive power and voltage stability in transmission, distribution and load, and the importance of providing reactive power locally. The description of selected control features of shunt power systems such as SVC (Static Var Compensator) – static compensators of reactive power, STATCOM-type systems (Static Compensator), static reactive power generators and systems that combine both these solutions, which are referred to as SVC based on STATCOM were not left out.

Index Terms – Reactive Power, Voltage stability, SVC, STATCOM, Voltage collapse, Voltage control.

1. INTRODUCTION

In the power system operation the control of voltage and reactive power is a major and important issue. This is because of the topological differences between distribution and transmission systems, different strategies have evolved. This review paper contains contributions of novel reactive power control and voltage stability methods for distribution and transmission systems. A particular interest is taken to the development of control methods to avoid so called voltage collapse, which can result in widespread outages [1]. In order to achieve efficient and reliable operation of power system, the control of voltage and reactive power should satisfy the following objectives [1].

- Voltages at all terminals of all equipment in the system are within acceptable limits.
- System stability is enhanced to maximize utilization of the transmission system.
- The reactive power flow is minimized so as to reduce $I^2 R$ and $I^2 X$ losses.

From this it can be concluded that the transmission system operates mainly for active power. Thus the vast numbers of loads are feeding power from the many generator units. Thus there is a problem of maintaining voltages within required limits; so as to maintain the reactive power demand. And as the load varies, the reactive power requirements of the transmission system vary.

Since the reactive power cannot be transferred or transported over long distances, voltage control has to be effected by using special devices located through the system which possess difficulties in keeping sufficient levels of voltage and reactive power in the power system network. This has been occurring practically since the first power systems started. Increasing requirements regarding both the supply reliability and quality of supplied power force using more modern devices. The proper selection and coordination of equipment for controlling reactive power and voltage stability are among the major challenges of power system engineering. These challenges gave birth to some selected devices to control or compensate reactive power. In order to cover reactive power and maintain the ability to control voltage stability within the target range, various sources of reactive power, such as SVC (Static Var Compensator) – static compensators of reactive power, STATCOM-type systems (Static Compensator) static reactive power generators and systems that combine both these solutions, which are referred to as SVC based on STATCOM. All power transported or consumed in alternating current networks, supply or consume two of powers: real power and reactive power.

Reactive power is necessary to move active power through the distribution and transmission system to the customer. For AC systems, voltage and current pulsate at the system frequency. Although AC voltage and current pulsate at same frequency, they peak at different time power is the algebric product of voltage and current. Real power is the average of power over cycle and measured by volt-amperes or watt. The portion of power with zero average value called reactive power measured in volt-amperes reactive or vars.

2. REACTIVE POWER CONTROL IN ELECTRICAL SYSTEMS

During the daily operation, power systems may experience both over-voltage and under-voltage violations that can be overcomed by voltage/Var control [1].Through controlling the production, adsorption, and flow of reactive power at all levels in the system, voltage/Var control can maintain the voltage profile within acceptable limit and reduce the transmission losses. Transmission connected generators are generally required to support reactive power flow. For example, Transmission system generators are required by the Grid Code Requirements to supply their rated power between the limits of 0.85 power factor lagging and 0.90 power factor leading at the designated terminals. The system operator will perform switching actions to maintain a secure and economical voltage profile while maintaining a reactive power balance equation:

$$G - M + Sg + Sc = [M - D + R + Sr] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,

G = Generator, M = MVARs, Sg = System gain, Sc = Shunt Capacitor, D = Demand, R = Reactive losses, Sr = Shunt reactors. The system gain is an important source of reactive power in the above power balance equation, which is generated by the capacitive nature of the transmission network itself. By making decisive switching actions in the early morning before the demand increases, the system gain can be maximized early on, helping to secure the system for the whole day. To balance the equation some pre-fault reactive generator use will be required. Other sources of reactive power that will also be used include shunt capacitors, shunt reactors, Static VAR Compensators and voltage control.

2.1 Reactive Power Theory

The reactive power is defined in the IEEE Standard Dictionary 100-1996 under the energy "magner" as:

$$\text{Reactive Power} = \sum_{n=1} \mathrm{Vn.\,In} \sin\theta \ldots\ldots\ldots.. (2)$$

where Vn and In are respectively the voltage and current rms values of the nth harmonics of the line frequency, and In is the phase difference between the voltage and the current nth harmonics. A convention is also adopted stating that the reactive energy should be positive when the current is leading the voltage (inductive load).In an electrical system containing purely sinusoidal voltage and current waveforms at a fixed frequency, the measurement of reactive power is easy and can be accomplished using several methods without errors. However, in the presence of non-sinusoidal waveforms, the energy contained in the harmonics causes measurement errors. According to the Fourier theorem any periodic waveform can be written as a sum of sin and cosine waves. As energy meters deal with periodic signals at the line frequency both current and voltage inputs of a single phase meter can be described by –

$$V(t) = \sum_{n=1}^{\infty} \mathrm{Vn}\sqrt{2}\sin(n\omega t) \quad \ldots\ldots\ldots... (3)$$

$$I(t) = \sum_{n=1}^{\infty} Vn\sqrt{2}\sin(n\omega t + \emptyset) \ldots\ldots\ldots (4)$$

The average active power is defined as:

$$\text{Average active power} = \sum_{n=1}^{\infty} Vn.In\cos(\emptyset) \ldots... (5)$$

Where,

Vn and In are defined as in Equation 2. The average active power is defined as: The implementation of the active power measurement is relatively easy and is done accurately in most energy meters in the field. The apparent power is the maximum real power that can be delivered to a load. As Vrms and Irms are the effective voltage and current delivered to the load,

$$\text{Apparent power} = \text{Vrms. Irms} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The correct implementation of the apparent energy is bound by the accuracy of the rms measurements.

2.2 Importance of Reactive Power

For the proper operation of electrical equipment voltage control in an electrical power system is important, to prevent damage such as overheating of generators and motors, to reduce transmission losses and to maintain the ability of the system to withstand and prevent voltage collapse. In general terms, decreasing reactive power causing voltage to fall while increasing it causing voltage to rise. A voltage collapse occurs when the system try to serve much more load than the voltage can support. When reactive power supply lower voltage, as voltage drops current must increase to maintain power supplied, causing system to consume more reactive power and the voltage drops further . If the current increases too much, transmission lines go off line, overloading other lines and potentially causing cascading failures. If the voltage drops too low, some generators will disconnect automatically to protect themselves. Voltage collapse occurs when an increase in load or less generation or transmission facilities causes dropping voltage, which causes a further reduction in reactive power from capacitor and line charging, and still there further voltage reductions. If voltage reduction continues, these will cause additional elements to trip, leading further reduction in voltage and loss of the load. The result in these entire progressive and uncontrollable declines in voltage is that the system unable to provide the reactive power required supplying the reactive power demands.

2.3 Effects of Reactive Power

Reactive power cause harmful effects on appliances and other motorized loads, as well as electrical infrastructure. Since the current required to do the necessary work is quite lower than the current flowing through electrical system. Excess power dissipates in the form of heat as the reactive current flows through resistive components like wires, switches and transformers. It makes no difference whether the energy is expended in the form of heat or useful work. We can determine how much reactive power your electrical devices use by measuring their power factor, the ratio between real power and true power. A power factor of 1 (i.e. 100%) ideally means that all electrical power is applied towards real work. Homes typically have overall power factors in the range of 70% to 85%, depending upon which appliances may be running. Newer homes with the latest in energy efficient appliances can have an overall power factor in the nineties. The typical residential power meter only reads real power, i.e. what you would have with a power factor of 100%. Clearly electric companies benefit from power factor correction, since transmission lines carrying the additional (reactive) current to heavily industrialized areas costs them money.

2.4 Voltage and Reactive Power Control Methods

Voltage and reactive power control involves proper coordination among the voltage and reactive power control equipment in the distribution system to obtain an optimum voltage profile and optimum reactive power flows in the system according to the objective function and operating constraints. Properly locating and sizing shunt capacitors will decrease power losses. The voltage profile in the distribution system can be improved by the proper capacitor selection. The capacitor locating and sizing is studied and executed in the planning stage of the distribution system. Most recently, many researchers have addressed the problem of voltage and reactive power control in distribution systems by focusing on automated distribution systems, such. At the moment, the voltage and reactive power control based on automated distribution systems can be divided into two categories: off-line setting control and real time control. The application of dispatch schedule based load forecasting is motivated by the fact that although there is a random fluctuation in the load variation, the major component of the load variations is related to weather conditions. Furthermore, there is a deterministic load pattern during the day due to social activities. It can be forecasted one-day-ahead with an average error less than 2%. Different objective functions and operating constraints have been proposed in voltage and reactive power control with automated distribution systems. Another objective that is commonly proposed is flattering the voltage profile. The automated control with off-line setting proposed in fully replaces the local control operation of the capacitor operations with a remotely controlled operation. The main obstacle application of this method is its dependency on communication links and remote control to all capacitors.

2.5 Ways of Improving Voltage Stability and Control

Reactive power compensation is often most effective way to improve both power transfer capability and voltage stability. The control of voltage levels is accomplished by controlling the production, absorption and flow of reactive power. The generating units provide the basic means of voltage control, because the automatic voltage regulators control field excitation to maintain scheduled voltage level at the terminals of the generators. To control voltage throughout the system we have to use addition devices to compensate reactive power. Reactive compensation can be divided into series and shunt compensation. It can be also divided into active and passive compensation. But mostly consideration will be focused on shunt capacitor banks, static var compensator (SVC) and Static Synchronous Compensators (STATCOM), which are the part of group of active compensators called Flexible AC Transmission Systems (FACTS). The devices used for these purposes may be classified as follows:

- Shunt capacitors
- Series capacitors
- Shunt reactors
- Synchronous condensers
- SVC
- STATCOM

(a) Shunt Capacitors

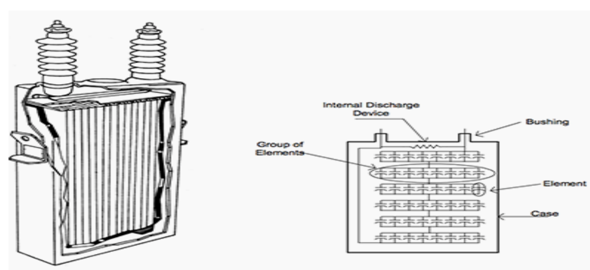

Figure (a) Capacitor Bank

The shunt capacitors and series capacitors provide passive compensation to the power system. To the transmission and distribution system they are either permanently connected or switched. The active compensation is provided by the synchronous condensers, SVC and STATCOM. Voltages at other locations in the system are determined by active and reactive power flows through various elements, including the passive compensating devices. The primary purposes of transmission system shunt compensation near load areas are voltage control and load stabilization. At major substation in load areas mechanically switched shunt capacitor banks are installed for producing reactive power. It is also helpful for keeping voltage within required limits. For voltage stability shunt capacitor banks are very useful in allowing nearby generators to operate near unity power factor. Compared to SVCs, mechanically switched capacitor banks have the advantage of much lower cost. The switching speeds of the shunt capacitors are quite fast. Current limiting reactors are used to minimize switching transients. There are several disadvantages to mechanically switched capacitors. For voltage emergencies the shortcoming of shunt capacitor banks is that the reactive power output drops with the voltage squared. For transient voltage instability the switching may not be fast enough to prevent induction motor stalling.

(b) Synchronous Condensers

Every synchronous machine (motor or generator) has the reactive power capabilities the same as synchronous generators. Synchronous machines that are designed exclusively to provide reactive support are called synchronous condensers. Synchronous condensers have all of the response speed and controllability advantages of generators without the need to construct the rest of the power plant. They also consume real power equal to about 3% of the machines reactive-power rating. Synchronous condensers are used in transmission systems: at the receiving end of long transmissions, in important substations and in conjunction with HVDC converter stations. Small synchronous condensers have also been used in high-power industrial networks to increase the short circuit power. The reactive power output is continuously controllable.

(c) Static synchronous compensator (STATCOM)

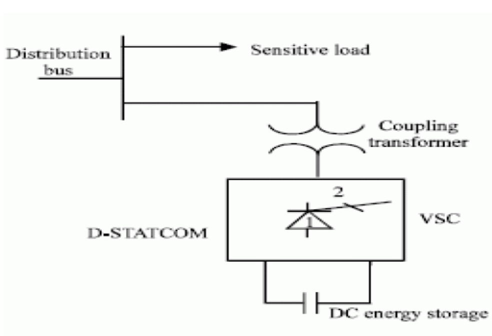

Figure (c) Static synchronous compensator

The STATCOM is a solid-state shunt device that generates or absorbs reactive power. It is one member of a family of devices known as flexible AC transmission system (FACTS) devices. The STATCOM is similar to the SVC in response of speed, control capabilities, and the use of power electronics. Consequently, output capability is generally symmetric, providing as much capability for production as absorption. The solid-state nature of the STATCOM means that, similar to the SVC, the controls can be designed to provide very fast and effective voltage control. While not having the short-term overload capability of generators and synchronous condensers, STATCOM capacity does not suffer as seriously as SVCs and capacitors do from degraded voltage. STATCOMs are current limited so their MVAR capability responds linearly to voltage as opposed to the voltage-squared relationship of SVCs and capacitors.

(d) Series Capacitors and Reactors

Series capacitors compensation is usually applied for long transmission lines and transient stability improvement. Series compensation reduces net transmission line inductive reactance. The reactive generation I^2X compensates for the reactive consumption I^2X of the C transmission line. Series capacitor reactive generation increases with the current squared, thus generating reactive power when it is most needed. This is a self- regulating nature of series capacitors. At light loads series capacitors have little effect.

3. CONCLUSION

In this paper, some representative techniques of reactive power and voltage control methods are reviewed. The advantages and disadvantages are studied. The future challenge is how to efficiently and accurately solve the problem taking into consideration the dynamic nature of power systems. In its entirety, it detailed background information on the on several fundamental properties of reactive power and the consequences of shortages in reactive power reserves. These issues are especially difficult because of the complex interaction between real and reactive power, from an engineering point of view, and from economic point of view. It also explained the fundamentals issues on Reactive power dispatch in electric power system, as a means of injection of reactive power into the system on the generators for improving voltage stability condition when the system in heavily loaded situation.

REFERENCES

[1] AkwukwaegbuI.O,Okwe Gerald Ibe, “Concepts of Reactive Power Control and Voltage Stability Methods in Power System Network”, *IOSR Journal of Computer Engineering (IOSR-JCE),* 2278-0661,ISSN: 2278-8727,Vol.11, Issue 2,May. - Jun. 2013, pp. 15-25.

[2] Carson W. Taylor, “Concepts of Undervoltage Load Shedding for Voltage Stability”, *IEEE Transactions on Power Delivery*, Vol. 7, No. 2, April 1992.

[3] C.D. Vournas, P.W. Sauer, and M.A. Pai. Relationships between Voltage and Angel Stability of Power Systems. “*International Journal of Electrical Power and Energy Systems”*, 18:493-500, March 1996.

[4] Claudia Reis António Andrade F.P. Maciel’ “Voltage Stability Analysis of Electrical Power System’’, *IEEE Transaction,* March 2009, pp.244-248.

[5] Namrata Baheshwar, Prof. A. Pachori, “Enhancement of Voltage Stability on IEEE 14 Bus Systems Using Static VAR Compensator”, *International Journal of Recent Research in Electrical and Electronics Engineering (IJRREEE)* ,Vol. 2, Issue 2, pp: (211-214), Month: April 2015 - June 2015.