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One approach for reactive power control of capacitor banks in distribution and industrial networks

Smajo Bisanovic [a,*], Mensur Hajro [b], Mersiha Samardzic [b]

[a] PE Elektroprivreda of Bosnia and Herzegovina, 71000 Sarajevo, Bosnia and Herzegovina
[b] Faculty of Electrical Engineering, University of Sarajevo, 71000 Sarajevo, Bosnia and Herzegovina

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ABSTRACT

This paper presents an efficient solution for reactive power control of capacitor bank using changes in reactance of connected reactor. This solution ensures smooth control of reactive power of capacitor banks as important operational characteristic for maintaining the quality of supply. The proposed method works for a wide-range of reactive power variations in the system and is capable of injecting or absorbing reactive power when necessary. This control method can be successfully used in distribution and industrial networks where many loads vary their demand for reactive power. Other applications of this method are voltage regulation, power-factor correction and reactive power compensation. The effectiveness of the proposed method is demonstrated through the case studies in order to prove its feasibility for improvement of voltage profile and reduction of power losses.

Introduction

Reactive power control has been recognized as a significant factor in design and operation of transmission and distribution (and industrial) networks for a long time. The rapid development and relative economy of shunt compensation devices led to their almost displacing of synchronous condensers in the transmission networks. At the same time, shunt compensation devices installed in distribution and industrial networks have become the best way to improve of voltage regulation, power-factor correction, load (phase) balancing and the handling of harmonics. Reactive power control is very important operational function for maintaining the quality of supply, particularly in preventing voltage disturbances that are the most frequent type of disturbance. Certain types of industrial load, including electric furnaces, rolling mills, mine hoists and dragline excavators, impose on the supply large and rapid variations in their demand for reactive power and it is often necessary to compensate for them with voltage stabilizing equipment in the form of static reactive power compensators [1,2].

Voltage regulation becomes an important and sometimes critical issue in the presence of loads that vary their demand for reactive power [3–8]. All loads vary their demand for reactive power, although they differ widely in their range and rate of variation. In all cases, the variation in demand for reactive power causes variation in the voltage at the supply point that can interfere with the efficient operation of supply network, giving rise to the possibility of interference between loads belonging to different consumers. Compensating devices have an essential role to play in maintaining supply voltages within the intended limits [9–13].

In most industrial harmonics networks, the primary objective for installing capacitor banks is to meet the utility power factor requirements. Additional benefits are better voltage regulation and lower losses. Any capacitor banks can be a source of parallel resonance with the system inductance. The best approach to avoid resonance problems is to install large capacitor banks at the main bus. This solution offers the following advantages: (i) more available reactive power to the network as a whole, (ii) easier control of harmonic voltages and currents, (iii) lower capital costs, as large banks are more economical in terms of purchase cost and (iv) reactors can be added to shift the resonant frequency away from the characteristic harmonic frequency of the plant [3].

For reactive power control in distribution and industrial networks mainly used capacitor bank configurations realized through changing the connection scheme certain number of capacitor sections according reactive load requirements. In these applications mechanically switched capacitor banks [14–16] are the most economical reactive power compensation resources. They are a simple, no effect on the short-circuit power and low-cost, but low-speed solution for voltage control and network stabilization

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* Corresponding author. Address: PE Elektroprivreda of Bosnia and Herzegovina, Vilsonovo setaliste 15, 71000 Sarajevo, Bosnia and Herzegovina. Tel.: +387 33 751 371; fax: +387 33 751 302.

E-mail address: s.bisanovic@elektroprivreda.ba (S. Bisanovic).

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under heavy load conditions. Newer solutions enable change of reactive power from capacitor banks as smooth output or output in very small blocks. These solutions contain a minimal number of switches and become very rational.

One of the most important problems related to the planning of electrical distribution and industrial networks is selection of the optimal size and allocation of capacitor banks. In the recent literature a numerous techniques for solving this problem have been used. For example, the works presented in [17,18] search the optimal location of capacitor banks and voltage regulators in distribution networks. The strategy proposed in [17] involves the allocation of capacitor banks with specification for the type of bank (fixed or automatic) and reactive power, as well as the allocation of voltage regulators with adjustment of their secondary voltage. For allocating voltage regulators and fixed or switched capacitor banks in radial distribution systems, the proposed model in [18] evaluates the set of equipments most appropriate to be installed. In [19] optimal capacitor bank sizes are determined using an efficient heuristic method, while appropriate capacitor bank locations are identified using nodes stability-indices. The proposed technique in [20] finds optimal locations for shunt capacitor banks from the daily load curve and it determines the suitable values of fixed and switched capacitors. A dynamic model considering multiperiod capacitor banks allocation problem of the primary radial distribution system is proposed in [21]. In reference [22] a new dynamic reactive power control method for the micro grid that is designed for small scale unbalanced distribution systems is presented. This method dynamically coordinates between voltage and reactive power generation and consumption to keep the bus voltages close to their nominal value.

The static VAr compensator is one of the modern power electronics equipment that ensures fast and continuous capacitive and inductive power supply to the electric power system. Generally, there are two approaches to the realization of power electronics based on VAr compensators: the first one that uses thyristor-switched capacitors and reactors and the second that uses self-commutated static converters [13]. Different configurations and arrangements thyristor-switched capacitors (TSC), binary thyristor-diode-switcher capacitors, thyristor-controlled reactors (TCR), thyristor-controlled reactor with shunt capacitor are used depending on application. All these arrangements have their own advantages and disadvantages especially when it comes to a continuous range of reactive power control, generation of harmonics components during the control process, sometimes uneconomical construction, etc. Static compensators combined with TSC and TCR are more advanced configurations characterized by a continuous control, practically no transients, low generation of harmonics and flexibility in control and operation. Significant progress of gate commutated semiconductor devices has attracted attention on self-commutated VAr compensators, capable of generating or absorbing reactive power without requiring large banks of capacitors or reactors.

While searching for solutions that would ensure continuous range of reactive power control, we have investigated a design of compensator that is presented in this paper. The design is based on the arrangement of the capacitor bank composed of 9 sections and the reactor. With this arrangement it is possible to ensure smooth control of reactive power by using change of reactor reactance, which is the main contribution of the paper. The proposed solution has an attractive theoretical simplicity and represents motivation for further researches (behavior of compensator in dynamic simulations, analyses of harmonics and flickers, etc.). It seems to us that thyristor-controlled reactor would be a good solution. This compensator would be installed on MV buses like a shunt compensator.

Notation

The notation used throughout the paper is stated below:

U	applied line voltage in the network
m, n	positive real numbers
C_1, C_2, C_3	capacitances of individual capacitor units
X_1	impedance of the capacitor C_1
R, X	resistance and reactance of the connected reactor
X_0, X_P	reactance that represent zero and reactance that represent pole of function $Q = f(X)$
$X_{\min}$, $X_{\max}$	minimum and maximum value of reactance of the reactor
Q	reactive power of the capacitor bank with connected reactor (reactive power of the compensator)
Q_∞	reactive power of the capacitor bank with disconnected reactor
$Q_{\min}$, $Q_{\max}$	minimum and maximum value of reactive power of the compensator

Design and performance of compensator

The capacitor banks consist of several capacitors per phase, each of that is connected or disconnected, as needed, by mechanical (thyristor) switches. This capacitor arrangement has a control system that monitors the voltage. When the voltage deviates from the desired value by some preset error in either direction, the control switches in (or out) one or more capacitors until the voltage returns inside the defined range, provided that not all capacitors have been switched in (out). It is very important to note that because of the on/off nature of the capacitor banks control, the compensating current can change only in discrete steps as a result of control action. In medium voltage applications (distribution and industrial networks) the number of capacitor banks is limited to a small number (for example, three or four) because of the expense of the thyristor (or mechanical) switches. As a result, the discrete steps in compensating current may be quite large, giving somewhat coarse control.

The solution that provides a change of reactive power of capacitor banks continuously or in very small discrete steps and which should be economical rational, is presented in Fig. 1.

For analyzed bank arrangement, $C_2 = C_1/m$ and $C_3 = C_1/n$, where, in the general case, m and n are positive real numbers. For this connection, with $\underline{Z} = R + jX$ and $X = const$, it is not difficult to show that the condition:

$$\frac{1}{\omega C_1} = \frac{2}{3}\,\frac{1+m+3n}{m+n+mn}X$$

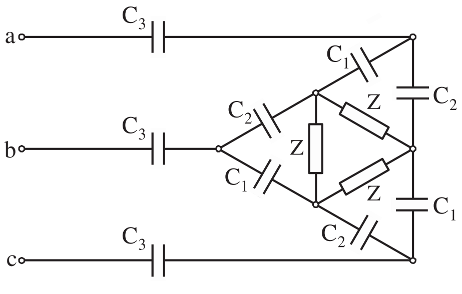

Fig. 1. The capacitor bank arrangement composed of 9 sections and reactor.