Distribution Series Capacitor Application for Improved Motor Start and Flicker Mitigation

D. McCarrel, R. Bahry, A. Folkesson, IEEE Member and P. Bérubé, IEEE Member

Abstract- **Voltage flicker can become a significant problem for power distributors when large motor loads are connected in remote locations. Installation of a series capacitor in the feeder strengthens the network and allows these loads to be connected to existing lines, avoiding more significant investment in new substations or new distribution lines.**

This paper describes a real-life application of a distribution series capacitor in Alberta, Canada where a long feeder is compensated to reduce flicker caused by infrequent start of large motors. To ensure performance within established feeder operating parameters, network simulation tools are used in design and engineering of the series capacitor. Overvoltage protection system and methods to detect and overcome problems related to subsynchronous resonance during start of large motors is also described.

This paper concludes that using distribution series capacitors is an effective and inexpensive method for network operators to connect large motor loads at the extremities of long distribution lines.

I. Introduction

The reactive power balance in an electrical network is regulated by the power system itself, power lines and electrical motors being the major users of reactive power, capacitors and synchronous machines being the contributors.

Only the active power produced by the active current is utilized at the point of consumption. The reactive power does not contribute to the conversion into useful power but is still necessary to be able to extract and use the active power.

The reactive power can be produced locally, by introducing series capacitors, to improve active power transfer by reducing the "electric length" of the line.

This paper presents a real application case. The Bassano series capacitor (March, 2005) was installed in an existing 25 kV feeder in FortisAlberta's distribution network in southern Alberta, Canada. The paper discuss several issues with regards to this application, such as:

- reasons for installing series compensation
- location in the circuit, degree of compensation
- protection by triggered gap
- flicker due to motor start
- damping of sub-synchronous resonance

A. Basic Theory

The basic theory of application of series capacitors is best demonstrated with the help of simple circuit and related phasor diagrams.

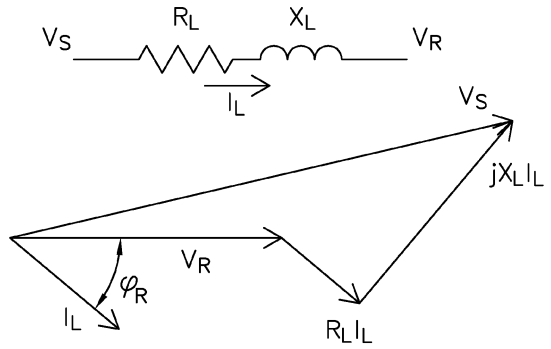

Fig. 1. Distribution line segment without series capacitor and related phasor diagram.

The voltage drop per phase along the line can be given as:

$$V_S - V_R = R_L I_L \cos\varphi_R + X_L I_L \sin\varphi_R \qquad (1)$$

Inserting a series capacitor in the circuit will counteract the inductive voltage drop with a phasor in the opposite direction:

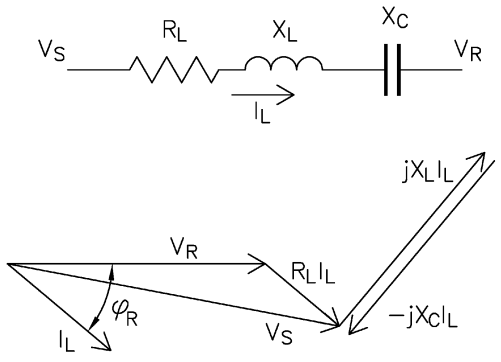

Fig. 2. Distribution line segment with series capacitor and related phasor diagram.

Fig. 2 above represents a typical series compensated radial circuit giving the total reactance in the circuit as:

$$X = X_L - X_C \qquad (2)$$

The resulting voltage drop can now be expressed as:

D. McCarrel and R. Bahry are with FortisAlberta Inc., Distribution Planning Section, 700, 801 – 7th Avenue SW, Calgary, T2P 3P7, AB, Canada

A. Folkesson and P. Bérubé are with ABB Inc., Systems division, 8585 route Transcanadienne, St-Laurent, H4S 1Z6, QC, Canada

0-7803-9193-4/06/$20.00 ©2006 IEEE.

$$V_S - V_R = R_L I_L \cos\varphi_R + (X_L - X_C) I_L \sin\varphi_R \quad (3)$$

The voltage drop along the line has decreased due to the insertion of the series capacitor. Consequently the voltage at the receiving end has increased. If the power consumed by the load in the receiving end remains constant it also means that the line current has decreased.

For a fluctuating load it is important to note that the resulting voltage improvement is completely governed by the actual load current in the line, i.e. the series compensation is inherently instantaneous and self-regulating.

A complete description of the basic theory for application of series capacitors in distribution networks is given in [1] where the following areas for application are discussed:

- improvement of the voltage profile
- reduction of voltage fluctuations
- reduction of required feeder reactive power input
- reduction of the circuit losses
- division of current between parallel circuits
- support during motor start

II. Bassano Series Capacitor Application

A. FortisAlberta, network and customers

FortisAlberta is a distribution network owner and supplier of electrical power to customers within 60% of the Province of Alberta in Canada. Alberta has a population of 3 million people and a surface area of 661,190 km^2 (256,000 sq miles). FortisAlberta has approximately 95,400 km (59,365 miles) of distribution circuits and serves 390,000 customers. Load growth averages 4% per year in the service area. Distribution feeders are long and radial in nature. The average length of a feeder is 45 km (28 miles) with the longest feeders approaching 100 km (62 miles). These long lines result in very low short circuit levels at the extremities of the distribution feeders.

The largest group of consumers is industrial, notably Oil and Gas producers. These customers utilize large motors ranging in size from 100 hp to 5000 hp that are usually located at the extremities of the distribution feeders. Due to low short circuit levels at these locations, this creates challenges for motor starting.

B. Voltage flicker assessment

FortisAlberta utilizes a load flow program, CYMDIST, to assess the distribution system capability to start a large motor while satisfying voltage flicker guidelines. The purpose of the voltage flicker guidelines is to ensure that the voltage fluctuation associated with motor starting by one customer does not create problems for other customers. Generally, this means that voltage fluctuation during infrequent motor starting should not exceed 5 % at the primary of the customer transformer.

C. Series capacitors in distribution networks

Over the last 11 years, FortisAlberta has installed seven series capacitors in different distribution feeders for the specific purpose of allowing large motors to be connected near the feeder extremities. The series capacitor ratings ranged from 8.1 ohms to 20 ohms. The installations have been very successful, as there have been minimal problems, to date. Fig. 3 shows a typical series capacitor installation.

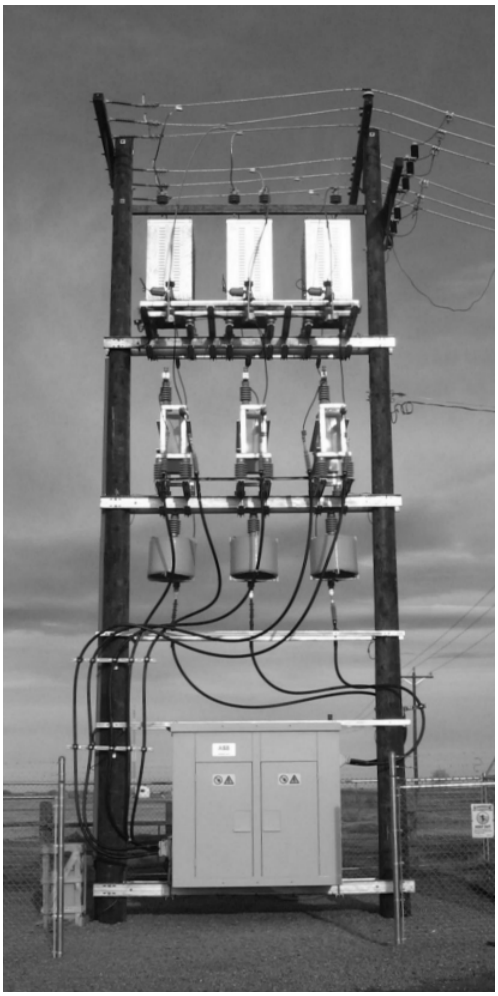

Fig. 3. 25 kV series capacitor installation at Bassano, AB, Canada.

D. Bassano series capacitor

Recently, a customer application resulted in a requirement for the installation of an additional series capacitor. In the Bassano service area in southern Alberta, FortisAlberta installed a new service to connect a 1750 hp squirrel cage induction motor for an Oil and Gas customer. The location of the customer site is approximately 43 km from the closest substation. The three phase distribution line from the substation to the large motor site utilizes 13.2 km of existing 397 MCM, 11.4 km of existing 266 MCM and 18.2 km of new 3/0 ACSR overhead conductor. The resulting short circuit level at the primary of the customer transformer is 26 MVA. As a rule of thumb, in order to meet the FortisAlberta voltage fluctuation guideline of 5 %, the rated power of the motor (hp) times 0.1 should be less than the short circuit level