Series Capacitors

Series capacitors are installed to reach a more efficient use of the transmission lines. The diversification of generation, transmission and distribution, in addition to long transmission distances and large generating power plants are resulting in an increased demand for economic and reliable operation of transmission systems. The demand for increasing power transfer means either more transmission lines or compensation of the existing lines. Series compensation is an economic method of improving power transmission capability of the lines.

Series capacitors will:
- increase power transmission capability
- improve system stability
- reduce system losses
- improve voltage profile of the lines
- optimize power flow between parallel lines

The cost of a series capacitor bank is approximately 10% of the cost of a new transmission line. Thus, the payback time for the series capacitor bank investment is only a few years.

Nokian Capacitors' experience

Nokian Capacitors is one of the leading manufacturers for high and low voltage capacitors, capacitor banks, air core reactors and control & protection systems for capacitor installations. Nokian Capacitors has been manufacturing compensation equipment since 1957. The factory is located in the city of Tampere, Finland, in modern premises and has modern automated machinery.

Nokian Capacitors exports 90% of its production.

In series compensation, Nokian Capacitors is one of the leading manufacturers in the world. Nokian Capacitors has been a pioneer in many solutions for the series compensation activities:

- First in the world complete solid state electronics 1964
- First in the world light-optic signal transmission 1964
- The biggest SC 1000 Mvar in the word 1971
- Fast reinsertion system for the word's biggest SC 1971
- First in the world fibre optic signal transmission 1975
- First in the world non-linear resistor scheme 1975
- The biggest SC 1056 Mvar in the word 1988
- Forced triggered Spark Gap & Metal Oxide Varistor 1989
- Digital Protection & Control System (NDP) 1994
- Capacitor unit sizes up to 1000 kvar 1995
- Laser powered signal transmission system for platform electronics 1997
- Forced triggered spark gap for Ulim 450 kV crest 2003
- Full scale seismic test 2003
- Staged line fault tests for numerous 500 kV and 735 kV series capacitor banks
- Full scale withstand voltage and RIV tests for 500 kV and 735 kV banks

Main features of Nokian Capacitors´ present series capacitor schemes:

- MOV scheme
- Laser powered signal transmission system for platform to ground communication
- Digital Protection & Control System, NDP+
- All controls and protection relays on ground level in the control room
- Integrated remote/local control and monitoring features
- Integrated communication software for SCADA communication
- Structural analysis for severe seismic condition verified by full scale seismic tests
- Tested and proven technology in different environments: Deliveries to extreme conditions: Canada and Finland -50º C, China & Brazil +45º C, India +50º C. Seismic design for word's most severe earthquake conditions: Atacama Chile
- Complete set of SC type tests including full size platform voltage withstand and RIV tests. Spark gap has been tested 40 kA 3 sec
- Patented capacitor unit fuse, damping circuit, spark gap and platform power supply
- Total delivered power over 19 000 Mvar in 50 projects
- The highest system voltage 750 kV

Different types of series capacitor schemes

Series capacitors are used to compensate the inductance of transmission lines. Series capacitors will increase the transmission capacity and the stability of the line. Series capacitors are also used to share the load between parallel lines.

Series capacitor schemes used today are:
1) Single gap scheme
2) MOV scheme
3) Thyristor Controlled Series Capacitor (TCSC)

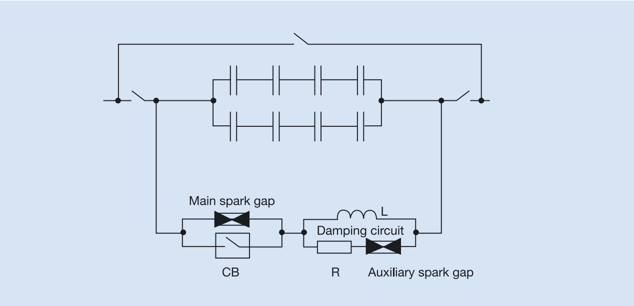

Fig.1 Single line diagram of spark gap protected series capacitor bank.

The Single Gap scheme (Fig. 1) can be called the original series capacitor scheme. It is simple and is used mainly where there is only one transmission line. In cases where there are two or more parallel lines, the MOV scheme (Fig. 2) is normally used.

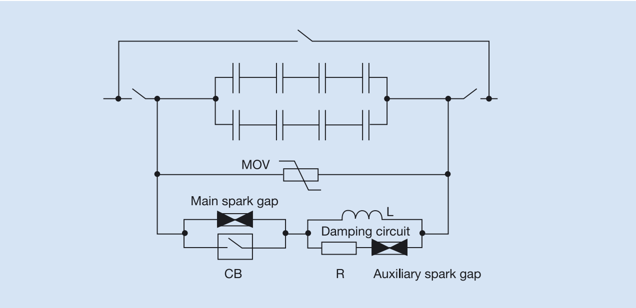

Fig.2 Single line diagram for MOV protected series capacitor bank.

In case of faults outside the line section, where the series capacitor bank is located, the MOV will protect the capacitors but the bank will not be bypassed. This will increase the stability of the transmission system.

The thyristor controlled scheme may be used to dampen oscillations in the line, when a weak network does not dampen the oscillations or they do not dampen sufficiently.

Nokian Capacitors has delivered both the single gap and MOV schemes, in Europe, North and South America and Asia, as well.

Nokian Capacitors, in consortium with Siemens, has also delivered a thyristor controlled series capacitor (Fig.3) to WAPA´s Kayenta series capacitor station in the USA.

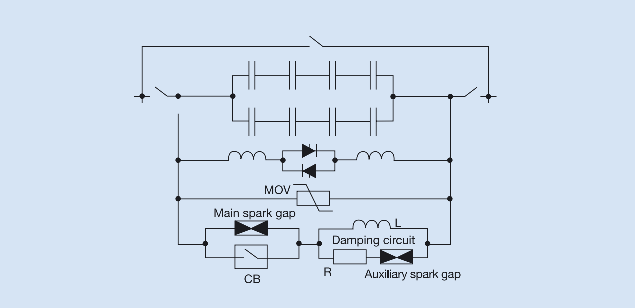

Fig. 3 Single line diagram for a thyristor controlled series capacitor bank.

Description of different equipment in series capacitor banks

LAYOUT AND MECHANICAL DESIGN

Layout

Depending on the size of the bank, each phase consists of one or two segments. The capacitor bank equipment is installed on a steel platform supported by insulator stacks and guy insulator strings rated for the system voltage.
A typical arrangement of a bank is shown in Fig. 4 and 5.

Mechanical design

The capacitor bank must be able to withstand the forces caused by short circuit, wind, ice, snow and earthquakes. These mechanical stresses are calculated by using finite element analysis.

In case of severe seismic requirements, it is not possible to design the bank without using special spring dampers in the string insulators. The natural frequency of the series capacitor bank is close to the frequency of an earthquake. The natural frequency of the bank will be reduced by suitable spring damping elements, which are designed by Nokian Capacitors for this application.

Control and protection system

The control and protection scheme for series capacitors is designed as an integrated system consisting of measuring transducers, a signal transmission system, a ground mounted control and protection system complete with human-machine-interface (HMI) and associated auxiliary services. The design philosophy for the control and protection system is to protect the capacitor bank and to ensure specified system operating requirements with high reliability and availability of the bank.

The signal transmission system forms an integral part of the control and protection system. It connects the measuring transducers and signal transmitters, located on the platform, to the signal receivers located in the control and protection cubicle inside the control building. It consists of a fiber optic signal column and fiber optic cables carrying signals from the platform to the control building. At platform level, the current signals are converted into infrared light signals, which are transmitted through the signal columns and fiber optic cables to the control building where these are converted into digital form, suitable for the control and protection system. A typical arrangement of the control cubicles and HMI is shown in Fig. 6.

The control and protection functions are fully implemented as software functions running in a computer system based on embedded controllers on a VME-bus. The software consists of protection relays, programmable control logic, system supervision and user interface modules.

The normal protective functions are capacitor unbalance protection, capacitor overload protection, capacitor sustained overvoltage protection, fault-to-platform protection, sustained spark gap protection, MOV single shot energy accumulation protection, MOV accumulated energy protection, MOV rate of energy rise protection, MOV overcurrent protection, MOV failure protection and subharmonic protection.

For remote operation of the series capacitors, the control and protection system is provided with a remote terminal unit with features based on the IEC 60870-5-101 protocol. The complete control and protection system is duplicated to achieve redundancy for all protective functions.

Special attention has been paid to the design to minimize equipment maintenance, thus enabling the series capacitor installation to operate unattended. Another goal in the design is to simplify maintenance and trouble shooting work.
A typical control and protection scheme for a series capacitor installation is shown in Fig. 7.

Fig. 4 301 Mvar 400 kV - 50 Hz series capacitor bank at Keminmaa substation in Finland.

Fig. 5 Series capacitor bank, 765 Mvar, 500 kV – 60 Hz at Ibiúna substation in Brazil.

Fig. 6 Typical arrangement of the control cubicles and HMI in the control building.

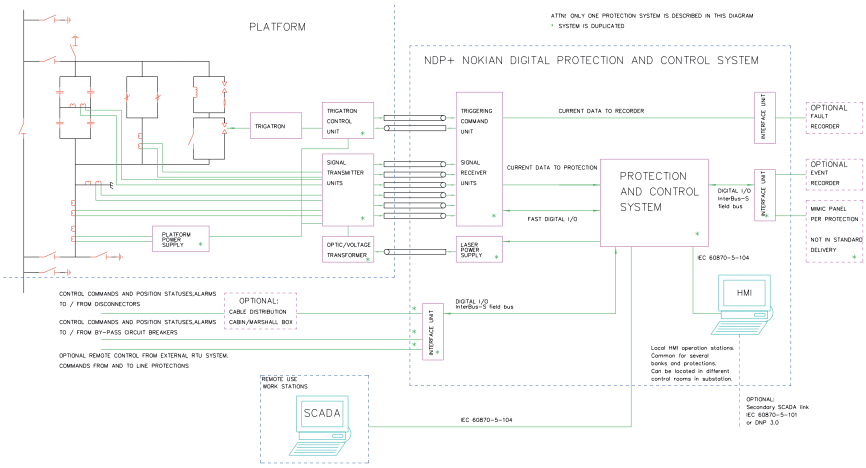

Fig. 7 Typical control and protection system arrangement.

Capacitor units

The capacitor units are of an all-film design with environmentally safe, biodegradable impregnation liquid. A large unit size is used for economical reasons and in order to minimize the size of the platform.

The units are equipped with internal fuses because of their technical and economical advantages.

Damping circuit

The damping circuit consists of an air core, dry type reactor with a parallel-connected damping resistor. In series with the resistor there is a small spark gap which connects the resistor to the circuit only during capacitor bank discharge and thus, minimizes the losses when the bank is bypassed.

Spark gap

The spark gap is a fast de-ionizing non-self-extinguishing spark gap. In case of operation of the MOV protection relay, the spark gap is forced triggered by the protection and control system via a light signal through the fiber optic signal column. The plasma arc in the Trigatron immediately triggers the spark gap.

Studies

Nokian Capacitors can carry out complete studies for the design of the series capacitor bank including system transient, fault analysis, seismic studies, protection coordination and other required studies.

References

Nokian Capacitors has delivered series capacitors to many power utilities like B.C. Hydro, Hydro Quebec, Western Area Power Administration, Furnas, Eletronorte, Fingrid, Norwegian State Power Board, Ministry of Energy of Vietnam (Electricity of Vietnam) and North China Grid Company.

Highlights

- Efficient method to maximise power transmission capability
- High availability with low maintenance costs
- High reliability with full redundancy
- Designed to endure severe conditions - from frost to heat
- Remote operability and service

Other products

In addition to series capacitors, Nokian Capacitors also manufactures:

- Static Var Compensators
- SVC MaxSine
- MaxSine active filters
- Railway series capacitors
- Air core reactors
- Shunt capacitor banks
- Filter capacitor banks
- High voltage capacitor units
- Low voltage capacitor units
- Control and protection system for capacitor banks
- Power factor controllers
- Unbalance relays
- Capacitance meters (clamp type)

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