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 increased demand for economic and reliable operation of transmission systems. The demand for increasing power transfer means either more transmission lines or compensation of lines. The 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 only approximately 10 % of the costs 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 and protection systems for capacitor installations. Nokian Capacitors has been manufacturing compensation equipment since 1957. The factory is located in the city of Tampere in Finland in modern premises and has modern automated machinery.

Nokian Capacitors is exporting 85 % 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 with solid state control and protection system in 1964
- first in the world with light operated signal transmission system in 1964
- fast de-ionizing spark gap in 1967
- first in the world with fiber optic signal transmission system in 1975
- first in the world with non-linear resistor protection scheme in 1975

Main features of Nokian Capacitors present series capacitor scheme:

- MOV scheme
- laser powered signal transmission system for platform to ground communication
- digital protection and 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

DIFFERENT TYPES OF SERIES CAPACITOR SCHEMES

Series capacitors are used to compensate the inductance of transmission line. 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.

The series capacitor schemes used today are:
1) Single gap scheme
2) MOV scheme
3) Thyristor controlled series capacitor (TCSC)

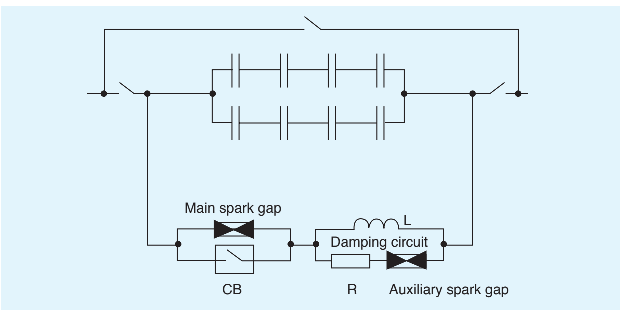

Fig. 1 Single line diagram of spark gap protected series capacitor bank.

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.

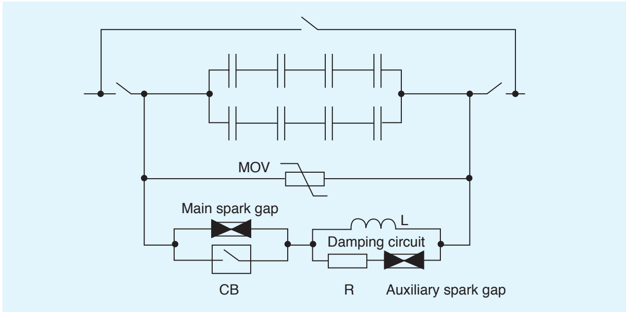

Fig. 2 Single line diagram for MOV protected series capacitor bank.

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 the weak network does not dampen the oscillations or these do not dampen sufficiently.

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

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

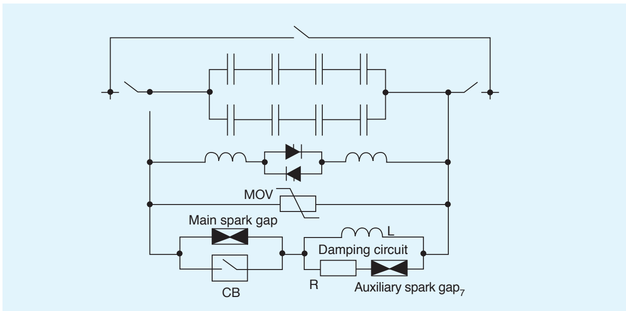

Fig. 3 Single line diagram for a thyristor controlled series capacitor bank.

DESCRIPTION OF DIFFERENT EQUIPMENT IN SERIES CAPACITOR BANKS

LAYOUT AND MECHANICAL DESIGN

Lay-out

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 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 protection and control scheme for the series capacitors is designed as an integrated system consisting of measuring transducers, signal transmission system, ground mounted protection and control system complete with human-machine-interface and associated auxiliary services. The design philosophy for the protection and control 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 protection and control system. It connects the measuring transducers and signal transmitters located on the platform to the signal receivers located in the protection and control 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. The typical arrangement of the control cubicles and HMI is shown in Fig. 6.

The protection and control functions are fully implemented as software functions running in a computer system based on embedded controllers on 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 shoot 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 protection and control system is provided with remote terminal unit features based on 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 in 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 protection and control scheme for a series capacitor installation is shown in Fig. 7.

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

Fig. 5 Series capacitor bank, 105.9 Mvar 400 kV - 50 Hz, at Uusnivala substation in Finland.

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

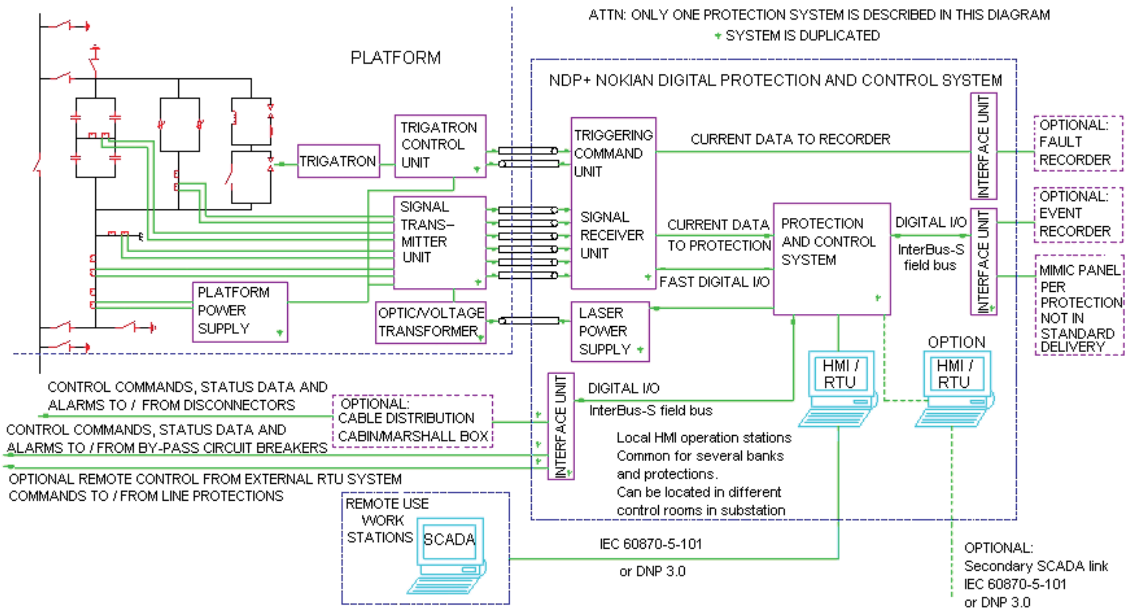

Fig. 7 Typical protection and control system arrangement.

Capacitor units
The capacitor units are of all-film design with environmentally safe biodegradable impregnation liquid. 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 into 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 triggers immediately 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 and Ministry of Energy of Vietnam (Electricity of Vietnam).

OTHER PRODUCTS

In addition to series capacitors Nokian Capacitors is also manufacturing:

- Static Var Compensators
- 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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