Connecting the London Underground

To take its power from the public grid, the London Underground closed its old 180 MW oil/gas fired power plant at Lots Road. Since the underground load consists mainly of diode converters that feed DC current to the trains, special measures had to be taken to limit or even prevent disturbances, such as voltage fluctuations and harmonics, from reaching the public grid. Extensive system studies were undertaken to map sources of distortion and identify the measures needed in order not to exceed the permitted disturbance limits at the points of common coupling.

In 2009, an SVC supplied and installed by ABB was commissioned for the 11 kV feeding grid to work together with several other ABB SVCs in operation since mid 2000. This brings to six, the number of SVCs, as well as a number of stand-alone harmonic filters that now operate at critical points of the London Underground 22 kV and 11 kV grid. Space issues and their proximity to underground stations – and thus large groups of people – meant the SVC installations had to be compact and completed in such a way as to confine noise and magnetic fields. For these reasons, the SVCs use iron-core TCR reactors instead of, more commonly, air-core reactors.

Mitigation of voltage fluctuations

It is a characteristic feature of traction loads to exhibit frequent big changes in active and reactive power. These power swings must pass through the impedance which exists between the feeding high voltage network and the load bus. Consequently, a significant source impedance is seen from the load bus and the load variations cause voltage fluctuations. Limits for the voltage fluctuations exist both on the feeding 132 kV network as well as on the low-voltage systems for traction load and auxiliary services. By means of SVCs located at the 22 kV and 11 kV system levels, reasonably low voltage fluctuations are attained both on the 132 kV buses and on 22 / 11 kV buses.

The 132/22 kV transformers are equipped with tap changers. The tap changers are used to compensate for slow voltage changes at the 22 kV voltage level, i.e. changes between peak load and low load periods. The SVCs compensate for load fluctuations only, thereby keeping the voltage fluctuations at the Point of Common Coupling (PCC) within limits. This is achieved by integration of the SVC reference towards a constant susceptance, using a slow time constant. This time constant must be short enough not to interfere with the tap-changer control and long enough to be able to reduce the load fluctuations.

Generally, voltage fluctuations at the 132 kV PCC are not allowed to exceed 1 %.

The required SVC sizes were determined in dynamic simulations, using loads that vary in time. The simulations showed that a substantial reduction of voltage fluctuations could be achieved by use of SVCs. This is demonstrated in Fig. 2.

Main circuit design

Each SVC consists of one TCR (Thyristor-controlled reactor) and a set of harmonic filters that are individually tuned and rated. By means of phase angle control of the TCR, a continuous variable output, from maximum Mvar capacitive to maximum Mvar inductive reactive power, can be obtained from steady state. Harmonic filter arrangements vary from site to site, depending on the fault level of the feeding grid at each site and the harmonic requirements (Fig. 3). The six SVCs can be sub-divided into three types (Table 1).

SVC type	Rated voltage, kV	Dynamic range, Mvar	Harmonic filter configuration
I	22	-27 / +33	3rd, 5th, 7th
II	22	-37 / +23	5th, 7th
III	11	-16.5 / +16.5	5th, 7th, 9th

Table 1: SVC types used in the London Underground

Thyristor-controlled reactors

Thyristor valves

The thyristor valves are equipped with BCT (Bidirectionally Controlled Thyristors). In such devices, two thyristors are integrated into one wafer with separate gate contacts. The two component thyristors in the BCT function completely independently of each other under static as well as dynamic operating conditions. Each component thyristor in the BCT has a performance equal to that of a separate conventional device of the same current carrying capability. The valve comprises only one thyristor stack in each phase instead of two, which offers considerable compactness of the valve design (Fig. 4).

Iron core reactors

In the TCRs, iron core reactors are utilized instead of, more commonly, air core reactors. There are a couple of reasons for this:

1) The scarceness of space in the London Underground environment forces a very compact physical design of the SVCs. This is fulfilled by iron core reactors, as compared to air core reactors.

2) Due to the close vicinity of the SVCs to populated parts of the Metropolitan area, magnetic clearance becomes an issue of importance. In this respect, iron core reactors are superiour

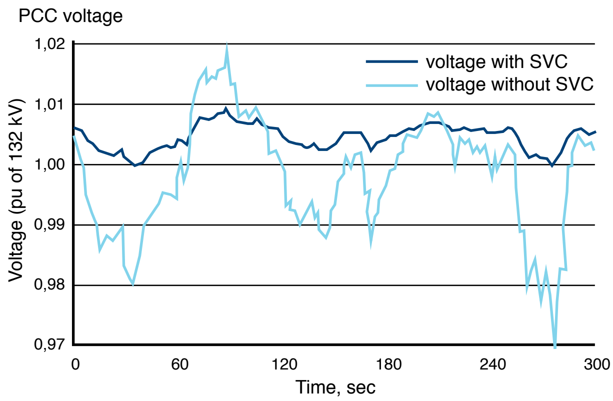

Fig. 2: Results from simulation of PCC voltage for the City Road system

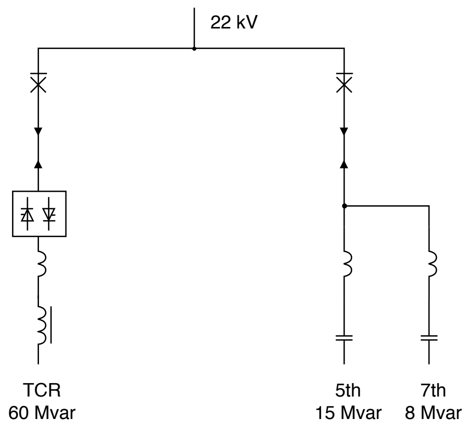

Fig. 3b: Single-line diagram, SVC Type II

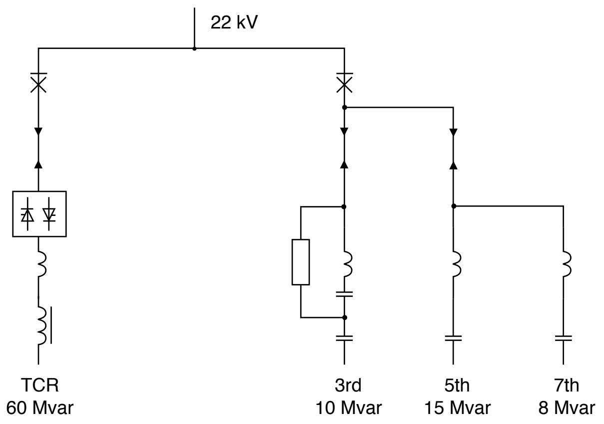

Fig. 3a: Single-line diagram, SVC Type I

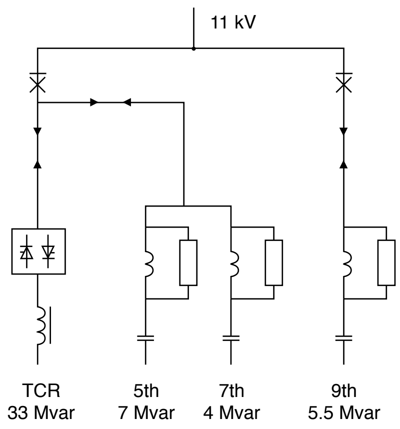

Fig. 3c: Single-line diagram, SVC Type III

to air core reactors, as well. The magnetic field is required not to exceed 1.6 mT at the boundary of any of the SVCs. Measurements have confirmed that this requirement is fulfilled.

SVC control

The reactive power operating range of each SVC is enabled by symmetrical control of the three phases of the TCR branch. The reactive power consumption of the TCR is continuously variable. The main task of the SVCs is voltage fluctuation control, with a nominal voltage of 22 or 11 kV. The voltage control system used is a closed loop system.

The control system is based on the ABB microprocessor based MACH 2 concept, which is a system of both hardware and software, specifically developed for power applications. MACH 2 is built around an industrial PC with add-in boards and I/O racks connected through standard type field buses like CAN and TDM.

The control system receives information from the network via VTs and CTs. Due to scarcity of space in the London Underground as well as considerations regarding visual impact, the physical locations of the SVCs are not necessarily coinciding with the best locations from an electrical performance point of view. To overcome this, the voltage response signal at the 22 / 11 kV bus is provided from a remote VT at the bulk supply point (BSP). The VT at the BSP is connected to a dedicated MACH 2 Data Acquisition Computer (DAC). The signal is transferred via an Integrated Service Digital Network (ISDN) to the MACH 2 control system located at the SVC. As a back-up, a redundant DAC and a MACH 2 are also connected to the remote VT at the BSP. If both ISDN connections are lost, the SVC will automatically switch to local control.

The control system allows operation of the SVCs either from local or remote. Local operation is performed from an Operator Work Station (OWS) located in the SVC control building (Fig. 5). Remote operation is done from a main control centre via a SCADA system. The SVCs are normally operated from remote.

Main technical data

SVC type	I	II	III
Number of SVCs	2	3	1
System voltage, kV	22	22	11
SVC rating, Mvar	-27/+33	-37/+23	± 16.5
TCR rating, Mvar	60	60	33
Harmonic filter rating, Mvar	33	23	16.5
Harmonic filter configuration	3rd, 5th, 7th	5th, 7th	5th, 7th, 9th
Control scheme	Symmetrical, closed loop three-phase voltage control		
Thyristor valves	BCT type thyristors, water cooled, indirect light firing		

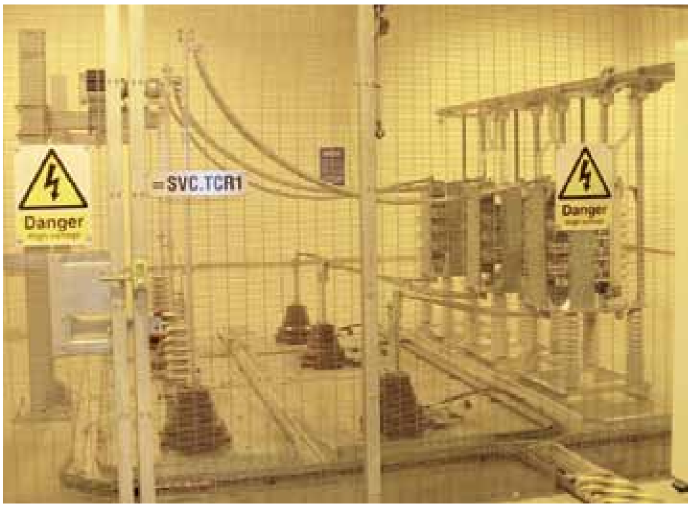

Fig. 4: Thyristor valve

Fig. 5: MACH 2 control system (right) and relay protection cubicles (left)

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