REGULATION SYSTEM FOR THE 18 KV/90 MVAR COMPENSATORS

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Abstract

Two 18 kV/90 Mvar static compensators are involved to stabilise the voltage, filter the harmonics and compensate the reactive power generated by the power converters used to supply the SPS accelerator magnets. The in-house hardware and software used by the regulation systems, difficult to maintain and upgrade, shall be renovated. Industrial solution based on PLC will be implemented. This paper describes the future system and its integration to the Electrical Network Supervisor.
1 INTRODUCTION

When operated as a proton accelerator, the SPS is a pulsed machine (see figure 1), and the Main Power Supplies (MPS), distributed in seven surface buildings around the accelerator, use most of the power. An extra load is composed of the Auxiliary Power Supplies (AUXPS) and the radio-frequency cavities (RF).

In the Electrical Building (BE), two 18 kV bus bars, each fed by an 18 kV/90 Mva transformer, are used to supply all these loads.

Due to the power source impedance (400 kV line and transformers), the voltage drop would be unacceptable during power swing caused by the MPS, and the voltage would be excessively polluted by the harmonics generated by the power converters.

To limit the load effects on the bus bars voltage, some actions shall be performed:
- The voltage must be stabilised.
- The reactive power swing must be compensated.
- The harmonics must be filtered, in order to reduce the Total Harmonic Distortion THD (u).

The voltage stabiliser system, the reactive power compensation system and the associated filter form a Static Var Compensator, noted SVC.

Regulation system are in charge to set the operating range of the voltage stabiliser whatever the load behaviour.

1.1 Reactive Power Compensation

The voltage stabiliser and reactive power compensation system is based on the parallel regulation principle. The device placed in parallel with the load is a saturated reactor. Due to the source impedance, an increase in consumption in the load is compensated by an equivalent decrease in the device. The sum is so kept stable, minimising the voltage swing due to the change in the load (see figure 2).

1.2 Main Components

The main components involved are the saturated reactor, the harmonics filters and the transformer equipped with a tap changer (see figure 4).

By design, the saturated reactor presents a constant voltage $V_s$ for a current maintained in the range $I_{\text{min}}$ to $I_{\text{max}}$, which corresponds to a reactive power swing $Q_{\text{min}}$ to $Q_{\text{max}}$. In order to compensate the slope of the function $u = f(I)$ in the saturated part, capacitors are serially connected with the reactor.

To filter the harmonics generated by the load and the saturated reactor, a shunted harmonic filter is installed. It is formed of branches tuned for harmonics 2, 3, 5, 7, 11, 13, 17 and a high frequency filter.

The 400/18 kV transformers is equipped with a 17-position tap changer. Increasing or decreasing the tap position modifies the reactor current, in order to operate the reactor within the saturated area. A voltage regulator crate is used as an interface to the tap changer.

1.3 Reactive Power Regulation

1.3.1 Process Mode

The regulation process is in STAND_BY when the SVC is disconnected from the network, or in OPERATION when the SVC is engaged.

In STAND_BY mode, the voltage relay is activated, and the Reactive Power Regulation process is set to IDLE. The voltage relay acts on the tap changer in order to keep the 18 kV bus bar at nominal voltage, in order to compensate the 400 kV line voltage changes.
On OPERATION mode, the voltage relay is inhibited and the Reactive Power Regulation process is activated. The regulation system sets the reactor current by moving the tap position through the motor control part of the voltage relay. The regulation system selects the nominal current in the reactor, depending on various possible modes. The regulation mode depends on the load behaviour, detected by permanently analysing the reactor current.

1.3.2 Regulation Mode

Permanently monitoring the reactor current, the system detects the load behaviour and selects the regulation mode in consequence.

When the power change during a cycle is higher than a predefined value, the load is considered as pulsing. The mode is then set to PULSED, and the tap position is set to keep the power excursion in the reactor within $Q_{\text{min}}$ to $Q_{\text{max}}$. A dead band corresponding to one tap change is considered. For $Q_{\text{max}}$, instantaneous and thermal consideration shall be considered.

During the SPS operation, the load may stop pulsing for some cycles or skip a cycle. As an example, for economical reasons, the function generators that compute the slope for the power converters can be set to zero when the beam is lost during injection from PS to SPS. In order to minimise the tap operations, a time delay is used to reduce the number of mode changes. During the delay, that starts when the load stops pulsing, the mode is set to IDLE and the load is supposed to start pulsing again anytime. The regulation conditions stay unchanged and no controls are issued. If the IDLE delay elapses the mode changes to WAIT.

If the load stops pulsing for a time longer than the IDLE delay, the mode goes to WAIT, and the regulation parameters are set in consequence. The load is supposed to start pulsing again anytime. If the WAIT delay elapsed, the mode goes to CAPACITIVE.

If the delay for the WAIT mode elapsed, or if the signal requiring CAPACITIVE mode is active (the power converters are stopped for more than 15 minutes), the regulation mode goes to CAPACITIVE. In that mode, the selected power in the reactor under compensates the filter power, therefore the reactive power through the transformer is capacitive.

When the load is signalled as consuming power, but no pulsed power is detected in the reactor, the load is in fact consuming continuous power (not pulsed). This happens after a pulsed period, when the last flat top continues for a long time. This mode occurred at the time the SPS was used in hadron collider mode and now during magnet and power converter tests periods. The regulation system shall control the reactor current in order to compensate for the 400 kV line voltage variations but must keep the reactor in condition to absorb the power back when the power converter will be stopped. If the power is kept too high in the reactor, it will trip when the reactive power will be released from the magnets.

1.4 Reactor Temperature Regulation

In order to guarantee the reactor characteristics, specially the voltage value at saturation and the $u=f(i)$ curve in the knee area, the reactor temperature must be kept within a specified range.

The reactor is cooled by three heat exchangers of type OFAF (oil forced, air forced), with one oil pump and three fans each. A temperature control process activates the number of fans required to keep the temperature at the selected value. The external causes for temperature changes are the atmospheric conditions, load mode changes (pulsed, stopped, coast, pulse shape) and the reactive power regulation set point. Due to the time constant induced by the mass of the reactor and the oil, a PID algorithm is required.

1.5 Local control

The regulation system shall provide tools to help the operators: Synoptic to display the various elements status and parameters settings, list of time tagged events in order to perform operation analysis, and graphical presentation of "real time" reactor reactive power and temperature evolution (see figure 3).
1.6 Remote control and monitoring

1.6.1 Integration to the ENS

The SCADA, core of the Electrical Network Supervisor (ENS), can manipulate entities commonly found in electrical network supervision, like status, counters and measurements. Most of the basic information, like I/O status, process and regulation mode, device operation counters, parameters, power and temperature measurements will be represented within the ENS. Archiving, alarms generation, data logging is defined at this level. The connection will use a JBUS/MODBUS protocol over an RS485 copper field bus segment.

1.6.2 Remote access

Complex entities like array of measurements, necessary to represent the SPS pulse shape can not be carried and manipulated within the ENS. Specialists will monitor these entities with dedicated tools and access method for analysis. This connection will use a TCP/IP connection over Ethernet, with OPC exchange method and embedded WEB server for direct HTML pages presentation to a standard WEB browser.

2 HARDWARE AND SOFTWARE

2.1 Hardware selection

The PREMIUM family PLC from Schneider Electric was chosen, for capability reasons and as already used within the group. A CPU with embedded regulation loop will provide the PID algorithm necessary for the temperature regulation. External adapter is required to adapt the reactor current measurement to the PLC analog input board capabilities. The local operator interface uses a touch screen with graphical capabilities within the MAGELIS family.

2.2 Programming

The PL7 PRO development tool is used for programming. Programming language is IEC1131 compliant, using ladder diagram (LD), function block diagram (FB), structured text (ST) or sequential function chart (SFC). Each section is programmed using the most appropriate language.

3 CONCLUSIONS

The CERN developed system based on MICENE, difficult to maintain and upgrade, will be replaced by industrial hardware and software solution and fully integrated in the ENS SCADA. This will permit an easier adaptation of the SVC regulation to future use of SPS as LHC injector.
Figure 1: Typical SPS pulse, seen at the 18 kV level.

Figure 2: Active, Reactive and Apparent power on transformers

Figure 3: Monitoring of the Reactor Power
Figure 4: The main components.