Commissioning of the Prototype 100 kV/36 A Power Converter for Klystron Tests

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1. Introduction

The converter consists of 3 main units:

i) a step down oil-filled transformer from 18 kV 3-phase to 1 kV 6-phase;
ii) a 6-phase A.C. thyristor regulator and
iii) a step up oil-filled 6-phase transformer incorporating the diode bridges and filter choke capable of delivering 100 kV D.C. at 36 A.

The first and third units were manufactured by Brentford Electric Ltd U.K. to a CERN specification and the second unit, which also consists of the regulation and protection electronics, was built at CERN.

Tests and evaluation started in February 1982 on an air-cooled high-voltage load and continued later on a salted water load. The completed unit was handed over to the LEP/RF group at the start of 1983 for further use with the klystron(s) as load.

2. Regulation and protection (Fig. 1 & 2)

Regulation and protection are carried out by the 6-phase A.C. thyristor regulator whose role is not only to regulate the output voltage but also to limit the fault current level and duration when the klystron protection crow bar is fired. The short-circuit capability of the converter is 40 MVA under such conditions.

A high-speed open loop 12-pulse firing circuit is used to control the thyristors. A first voltage loop working through an output model achieves the first level of stabilization and mains rejection. A second, slower loop, is closed around the high-voltage output divider and uses the remote controlled DAC as reference.
There are several levels of 'fast' protection. Separate hardwired connections are received from the spark-gap electronics and the klystron protection system, pre-warning the converter of the short-circuit condition. These signals are backed up by two overcurrent sensors monitoring the low-voltage current. On receipt of any such signal, the converter protection inhibits any further thyristor firing by blocking and phasing back, setting the reference DAC to zero and ordering the opening of the Main Circuit Breaker as an extra security.

3. Commissioning and evaluation

Apart from the normal commissioning routine, several points or problems were studied and in general solutions found or at least a better knowledge gained. These can be divided into five areas:

i) Thyristor/transformer configuration

The step up transformer was delivered with an open delta primary and star secondary. Initial tests were carried out with the thyristors connected in the delta, known as a delta controller, as shown in Fig. 3. The theoretical turns ratio under closed delta operation is 27:1 but this rises to 41:1 under phase-delayed firing when one primary coil must supply the ampere-turn balance for two or three secondaries. This has two adverse effects on the transformer. Firstly the r.m.s. current in the primary of the transformer for a given power throughput is increased and hence the power losses (see Photo 1). Secondly the coupling is low and a large quantity of flux passes through the tank walls, once again increasing losses, this time to an unacceptable level. Although this system maximized on thyristor utilization, the transformer losses could be considerably reduced by reconfiguring to a line controller at the expense of using twice the number of thyristors. A second aspect is that with the line controller two thyristors need to fail before energy is passed to the load compared with one in the case of the delta controller. With a line controller the primary kVA is reduced to 0.74 of the previous value with an attendant form factor improvement from 1.6 to 1.06. Thyristor thermal factor increases by 1.79. However, thyristors are much cheaper than power transformers.

Hence a line controller of a Delta/Star transformer will be used for LEP.
ii) Parasitic oscillations

The original 85 kVA/22 A supply had shown excessive parasitic oscillation after commutation, but the reason for this was not clear. The same was observed on the new converter and more detailed investigations made. The parasitic oscillation is not detrimental to klystron operation but increases the suppression losses in the converter. The phenomenon can in fact be observed in all thyristor commutating equipment, it is however more pronounced with the high values of inductance of the output coils in the high-voltage transformers. These interact with the parasitic capacitance of the windings (and any other) to earth and act as a shorted pulse-forming network to earth with little damping at each thyristor firing. This results in an oscillating current passing through the earth system and the windings of the transformers. The simplest solution was to significantly increase the impedance to earth at the oscillatory frequency, which was done by placing the main filter choke in the earth line (see Photo 2). In the final LEP converters the output choke will be split to give a symmetric arrangement and the parasitic capacitance to earth limited wherever economically possible.

iii) 18 kV Harmonic current generation on the 18 kV network

Measurements were made to verify that the basic chosen topology and the thyristor firing system generated only high order harmonic currents in order to reduce the risk of internetwork oscillation and the amount of harmonic filtering necessary. At an output level of 100 kV/36 A, no measurable current below the 11th and 13th harmonics could be observed, the 11th being 2.2% of the fundamental and the 13th being 4.3%. Photo 3 shows the input current drawn from the 18 kV Meyrin network at two output levels (Ps/c = 340 MVA).

iv) Response to crow bar operation

Several thousand crow bar short circuits were carried out in order to observe the reaction of the converter to such treatment and the response times. During these tests the longest observed current pulse was 7 milliseconds and the highest level was one-third the calculated worst case.
v) Thyristor/Heat sink corrosion

The large diameter (7.5 cm) capsule thyristors used in the regulator have a relatively low clamping pressure due to their large area. Pitting/corrosion had been observed after 5000 impulses of 12,000 A peak had been passed through the thyristor/heat sink combination. This was traced to local oxidation on the aluminium heat sink which is aggravated by the high current densities and low pressure. More careful machining and nickel plating produced the cure.

4. Operational experience to date

The converter has run for more than 350 hours and performed long-term heat runs at 38 A (Nominal current is 36 A). It has also powered two klystrons in parallel consuming 36.8 A total and performed a short run (3 1/2 hours) at 40 A. It has been short-circuited by the crow bar several thousand times with no apparent ill effects. Running experience will continue to be gained over the coming year in conjunction with the LEP/RF group's tests. Logging of data has recently been improved by the incorporation of a computer-orientated surveillance system similar to the type which will be used on the final converters of LEP.

5. Future configuration for LEP klystron converters (Fig. 4)

The basic topology as described in this note will be adopted for LEP. However some detail changes will be made in order to optimize the technical solution, reduce security problems and hopefully reduce the total cost of each converter. Briefly, the output rectifier bridges, filter chokes and other accessories such as the potential dividers will be separated from the step-up transformer and placed in their own oil-filled tank. This solution, while increasing the number of sub-units, does yield the following advantages:

1) limited fault propagation and contamination of expensive power transformers in the case of a fault in a fragile auxiliary component;

2) heaviest unit is now 30 tons (compared with previous 55 tons). Hence reduced transport and handling problems;
3) optimization of oil temperatures in each tank (the diodes need to run at a lower temperature than the transformers);

4) reduction of total quantity of oil, and of oil in any one unit. Hence less fire risk;

5) less specialized manufacturers needed and hence larger number of potential suppliers available to CERN.
Fig 2: REGULATION AND PROTECTION SCHEME

18kV

1kV

Y

VOLTAGE DIVIDER

FIRING SYSTEM ASAD 12

FEED-BACK MODEL

DAC

70Hz

1Hz

X

FAST PROTECTION

SET ZERO

BLOCK

PHASE BACK

18kV CIRCUIT BREAKER

X > I

Y > I

KLYSTRON (FAST)

SPARK GAP (FAST)
DELTA CONTROLLER

R

T

S

LINE CONTROLLER

R

T

S

FIGURE 3 — CIRCUIT CONFIGURATIONS
Fig 4: PROPOSED KLYSTRON CONVERTER LAYOUT FOR THE LEP MACHINE
PHOTO 1A - TRANSFORMER COIL CURRENT FOR DELTA CONTROLLER (I_{rms} = 460 A - OUTPUT 100kV/18A)

PHOTO 1B - TRANSFORMER COIL CURRENT FOR LINE CONTROLLER (I_{rms} = 340 A - OUTPUT 100kV/18A)

PHOTO 2A - LINE CURRENT PARASITIC OSCILLATION WITH CHOKE IN HIGH SIDE

PHOTO 2B - LINE CURRENT PARASITIC OSCILLATION WITH CHOKE IN EARTH SIDE

PHOTO 3A - 18kV INPUT CURRENT FORM AT 80kV/29A OUTPUT

PHOTO 3B - 18kV INPUT CURRENT FORM AT 100kV/36A OUTPUT