Mini-Review on CLIQ Units

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General aspects of the design, choice of components and safety issues

- The mandate to design, define and procure components, assemble, wire and test a first pre-series of 3 identical coupling-loss power sources was given to the MPE/Electrical Engineering section in early Febr. 2015 with the goal of shipping two tested units to Fermilab before 1 June and keeping one unit at CERN for further improvements in view of future requirements.

- Certain choices of components were determined by the very short delivery time for the first units i.e. extensive use of what we already have available and what we could get with short lead times.

- Obviously, also the resource organization was affected by the short lead time, with involvement of an important fraction of the section members.

- Many team members involved in the project have experience from designing and operating the present 6000 quench heater discharge power supplies (DQHDS) which today protect the superconducting magnets of the main dipole- and quadrupole chains as well as the IPQ/IPD circuits in the LHC.

- Although being of a different nature (only discharge) many technical features and safety aspects of the existing LHC discharge power sources have been taken over – at least as source of inspiration. New circuit topologies and different operating principles have been implemented in order to overcome observed weaknesses or improve reliability with respect to the existing heater supplies.

General aspects (1)

- The CLIQ power unit is not only a supply, it is an **energy exchanger** which, after a first discharge of its own stored energy, will receive back a part of the energy stored in the connected portion of the magnet coil, which again will be discharged into the coil –and so on. This will lead to the characteristic ringing, which is being increasingly damped by the resistances in the circuit, mainly the rapidly increasing resistance of the quenching coil, but also by the series-equivalent resistance of the capacitor bank. The ringing leads to both positive and negative voltages on the storage capacitors within one current direction.
- Capacitor selection:

The storage capacitor bank for CLIQ must, according to above considerations, be of **bipolar type**.

Further requirements: Low internal series-equivalent resistance, high capacitance density and require minimum busbar work for connection.

Selected type: **Self-healing, dry type, metallized polypropylene**

Data: 500 V, 2 x 40 mF, 2 x 44 kg. From LHC QF/QD snubber capacitor spares. With over-charge protection and over-pressure indication. Stored energy: 10 kJ.

- Charging: The LHC 3-step type of charger is replaced by a 100 mA constant-current charger of commercial origin - tailored to our application. Full charging time reduced to 200 s. Charging voltage shall be adjustable in steps of 50 V (manual commutation, up/down).
- Charging from 110 V, 60 Hz as from 240 V, 50 Hz.

Capacitor voltage and charging current shall be displayed as well as the end of charging state.

General aspects (2)

- The Discharge Characteristics:
  - Because of the bi-directional nature of the discharge / recharge currents, semiconductor switches in a bi-directional arrangement have been chosen.
  - Because of the good experience from the LHC quench discharge heater units with the use of thyristor switches this practice we will stay with thyristors for the CLIQ units.

  - Thyristors will be used in both directions in order to assure a 'certain separation' of the main magnet powering circuit from the heater circuit outside the provoked coupling period (no return diode shall be used). The two opposite thyristors shall be fired simultaneously for 1 s. No trigger redundancy in each unit is considered necessary.

Two candidate thyristors are presently being considered:

Fast Switching Thyristor
5STF 06D1620

Key Parameters

V_{DRM}	=	1600 V
I_{TAVM}	=	570 A
t_q	=	20 μs
I_{TSM}	=	8000 A
V_{TO}	=	1.10 V
r_T	=	0.750 mΩ

Single Thyristor used for fast opening pulse to LHC main circuit energy extraction switches (BCM). To be doubled.

Bi-Directional Control Thyristor
5STB 24N2800

V_{DM}	=	2800 V
$I_{T(AV)M}$	=	2430 A
$I_{T(RMS)}$	=	3820 A
I_{TSM}	=	43×10^3 A
V_{T0}	=	0.85 V
r_T	=	0.16 mΩ

Bi-directional Thyristor for energy management. Approved by ABB for the CLIQ application. Two thyristors in one wafer.

The thyristor firing shall be provoked through application of a train of pulses, from a 12 kHz generator through pulse transformers.

Discharge current shall be measured by adequate LEM transducer (6kA peak, 10^{-3} accuracy).

Safety aspects

- A main switch, located outside the CLIQ unit, shall assure not only interruption of the input power but equally switch-in a bank of discharge resistors which will assure an automatic ‘internal’ discharge of the complete capacitor bank. The total discharge time shall be 6 minutes maximum. In addition to a clear indication of the actual charging voltage, a visible indicator shall show safe conditions (<40V). The main switch shall be lockable.

- A warning label shall indicate this minimum waiting time before any intervention on the unit.

- In view of the high stored energy, each external panel of the CLIQ enclosure (mobile rack) shall be mounted with special safety screws which requires special tools for opening. In addition, the number of such screws per panel shall not allow opening in less than 6 minutes.

- After re-powering from the mains input, there shall be no automatic re-charging of the capacitor bank (system is latched). Charging shall be initiated manually.

- After a discharge the system is automatically latched. Recharging only by manual activation.

- Activation of the emergency stop shall initiate a discharge.

- Internal busbars and terminals of the power system will get local protection covers.

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