



Conceptual design of 2 MJ capacitive energy storage

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ABSTRACT

The conceptual design of the capacitive energy storage intended for operation in laboratory conditions is considered. This capacitive energy storage includes the capacitor cells of 200 kJ stored energy, each incorporating one self-healing high-energy-density capacitor, one semiconducting switch unit on the basis of Light Triggered Thyristors (LTT) and the pulse diodes, as well as the toroid inductor. Power supply of the capacitive energy storage is provided by high voltage (HV) 3×10 kV, 50 Hz industrial electrical network, using the HV power transformer and phase-controlled rectifier. Special design for the capacitor cell and the module of capacitor cells is proposed, which provides easy access to all components of the capacitor cells during operation and maintenance. Control system of the capacitive energy system has a hierarchic structure and includes programmable logic controller (PLC), programmer for non-synchronous triggering of capacitor cells discharges and data acquisition system.

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1. Introduction

Present-day capacitive energy storages are compact and highly reliable. Compactness is achieved by applying up-to-date high-energy-density capacitors with metallized electrodes. High reliability is provided by self-healing capacitors and semi-conductor discharge switches.

The problem of developing a compact capacitive energy storage arose sufficiently long ago [1] after appearance of capacitors with a high energy density. Some capacitive energy storages developed in recent years are described in the proceedings of the International Pulsed Power Conference and in scientific-technical journals [2–6]. Typical of all these energy storages is the following:

- Use of self-healing high-energy-density capacitors with metallized electrodes.
- Use of semiconductors in the discharge current switches.
- The capacitor bank is divided into capacitor cells, each incorporating one capacitor and one unit of semiconductor switch.
- The possibility is provided to switch on the switches in the cells not synchronously but by the preset time program (programmable discharge).

The paper considers the conceptual design of the capacitive energy storages possessing all above properties.

2. Technical requirements and characteristics

The technical requirements and characteristics of the capacitive energy storage are given in Table 1.

3. Capacitor cell

Large capacitive energy storages incorporate a set of capacitor cells. The capacitor cell of an up-to-date compact capacitive energy storage consists of, as a rule, one capacitor and one discharge current switch. Stored energy and discharge current of one cell are determined by the characteristics of the discharge current switch.

The main parameters of the capacitor cells are given in Tables 2, 3, 4. Fig. 1 presents the equivalent circuit of the capacitor cell.

The stored energy density in the capacitor cell is determined by the energy density in the main components (capacitor, inductor) and compact arrangement of the elements of this cell.

The compactness (high component density) is attained by mutual coordination of the arrangement and sizes of the main components of the capacitor cell (capacitor, inductor, semiconducting switch unit and others).

The following arrangement was proposed for the capacitor cells (Fig. 2):

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Table 1

Technical characteristics of capacitive energy storage.

No.	Characteristic	Source#1
1	Stored energy/mJ	2
2	Maximal voltage/kV	11
3	Maximal discharge current/kA	900
4	Number of capacitor cells	10
5	Charging duration, no more than/s	5
6	Consumed power/kW	880
7	Number of discharge triggering channels	10
8	Delay of discharge triggering pulses/ μ s	0
9	Module volume (without cable collector), no more than/ m^3	4
10	Resistance of load resistor/m Ω	2
11	Energy capacity of load resistor/mJ	20

Table 2

Technical requirements for capacitor cells.

No.	Parameter	Notation	Value
1	Number of capacitor cells	n	10
2	Maximal voltage/kV	U	11
3	Capacitance/mF	C_1	3.3
4	Stored energy/kJ	$W_1 = \frac{CU^2}{2}$	200
5	Inductance/ μ H	L_1	32
6	Discharge current maximum, not less than/kA	$I_m \geq 0.8 \frac{U\sqrt{C_1}}{\sqrt{L_1}}$	90
7	Capacitor discharge time/ μ s	$t_c \approx \frac{\pi}{2} \sqrt{L_1 C_1}$	510
8	Current pulse duration in short-circuit mode (at a level of 10% of amplitude), not less than/ms	p	15

Table 3

Dimensions, volume and energy density of capacitor cells.

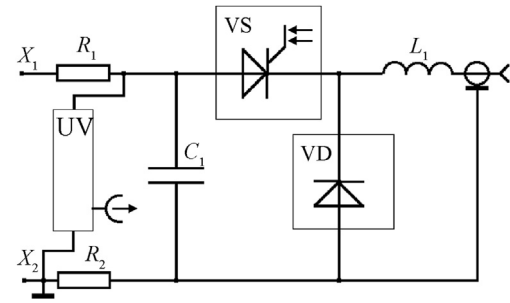
No.	Parameter	Notation	Value
200 kJ capacitor cell			
Capacitor with sizes			
1	Cell dimensions/mm ³	$H \times A \times B$	$1030 \times 480 \times 660$
2	Volume/dm ³	$V = H \times A \times B$	326.3
3	Energy density/(J·cm ⁻³)	$w = \frac{W_1}{V}$	0.613

- the cell should be without a bearing frame or metal frame;
 - all components of the cell should be arranged on and fastened to the capacitor case;
 - the capacitor case should be fastened to the frame of the capacitor module.
- Accordingly, the sizes and structure of the capacitor were chosen (Fig. 2), which provided the following:
- energy density in the capacitor $w = 1.5 \text{ J/cm}^3$;
 - the capacitor sizes match the arrangement of the cell equipment;

Table 4

Characteristics of pulse capacitors for 200 kJ capacitor cell.

No.	Characteristic	Values specified
1	Voltage/kV	11
2	Capacitance/mF	3.3
3	Stored energy/kJ	200
4	Current pulse amplitude/kA	120
5	Case dimensions $H \times A \times B$ (Fig. 2)/mm ³	$655 \times 500 \times 398$
6	Case volume/dm ³	130.3
7	Energy density/(J·cm ⁻³)	1.53

**Fig. 1.** Equivalent circuit of the capacitor cell.

VS – the assembly of LTT, VD – the assembly of crowbar diodes, UV – the voltage sensor (voltage divider with a signal converter).

- the steel case of the capacitor is made as a bearing element of the cell. This bearing element is fastened on the module frame and mounts the main components of the capacitor cell.

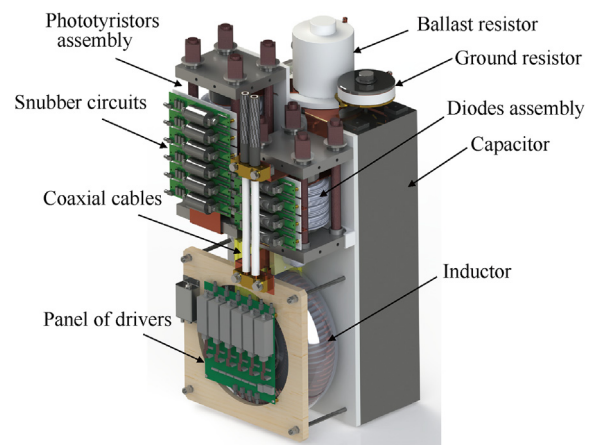
Toroidal wound inductors, as that shown in Fig. 3, will be used in the capacitive energy storage [11]. The advantages of these inductors are as follows: high energy density, high Q-factor and small leakage magnetic flux.

An important part of the inductor design is the contact unit in the left part of the torus, as shown in Fig. 3. This unit ensures an electric contact between the current-carrying busbars and inductor wires. During assembly the contact unit provides compression of contacts with a higher force, at which the current-carrying buses are plastically deformed along the contact line, providing a reliable contact with a low contact resistance between the busbars and inductor winding conductors [13]. Parameters of the inductor is presented in Table 5.

4. Switch unit of the capacitor cell

A semiconducting switch built on TF1193-2500-42 LTT and D193-2500-50 diodes made by JSC “Elektrovipryamitel”, Saransk, Russia was chosen for application in the capacitor cell. The semiconductor switch includes six LTTs and 4 diodes. The parameters of the operation modes of LTT and diodes are presented in Table 6.

Our studies of operation of semiconducting switches in pulsed facilities [7,8] have demonstrated that the maximal operating voltage on semiconductors should be, at least, by a factor of two

**Fig. 2.** Arrangement of the capacitor cell.

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