HIGH VOLTAGE MODULATORS BASED ON SOLID-STATE ELEMENTS FOR LINACS (REVIEW)

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The data on developing and creating high-voltage pulse modulators for linacs with using Insulator Gate Bipolar Transistors (IGBT) and Integrated Gate Commutate Thyristors (IGCT) are presented. Comparative analysis of main characteristics such as efficiency, reliability and cost are made for standard modulator and semiconductor high voltage sources with different scheme topology.

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1. INTRODUCTION

Development of such devices as POWER MOSFET, IGBT, IGCT made it possible to create modulators with the partial discharge of capacity, which have the following advantages:

a) ability to receive a good pulse shape close to rectangular, b) high efficiency, c) repetition rate and width of the output pulse can be adjusted by simply adjusting the trigger duration.

Their disadvantages are related with a necessity to use the condensers of a very large capacity with small leakages designed for the very high voltage.)

As the voltage of modulators usually is of about 250…500 κV and currents are in the range 150… 2500 A, it is obviously that the separate elements cannot satisfy given parameters. The solution of this problem is to connect as many switching devices in series as is needed to meet the application requirements. There are various circuit designs with the use of a partial discharge of capacity. All these circuit designs can be divided into two groups: so-called hybrid circuits, in which pulse transformers are used, and circuits without transformers.

2. HYBRID MODULATORS

During development of high efficient, highly reliable, and low-cost pulsed-power modulators designed to drive the NLC 500 κV, 230 A X band klystrons, one proposed [1] the solid-state induction modulator for the power supply of 8 klystrons with a peak output voltage U_{out}-500 κV; and peak output current I_{out}-2080A. The modulator is capable to supply rise/fall time <200 ns with pulse duration flat top 3 μs, voltage regulation flat top <±1%, and repetition rate 120 Hz. Thus the efficiency is expected more than 75%. The simplified modulator circuit is shown in fig.1. The modulator topology selected for the NLC modulator is similar to an induction accelerator. It consists of a large number of single-turn induction cores each driven by its own solid-state switch. In this configuration, the voltage on the secondary winding is the sum of all the voltage appearing on the primary windings. The resulting total leakage inductance at the secondary is low (<20 μhy).

In work [1] the results of testing the model of induction modulator consisting from 10 sections of cores are given.

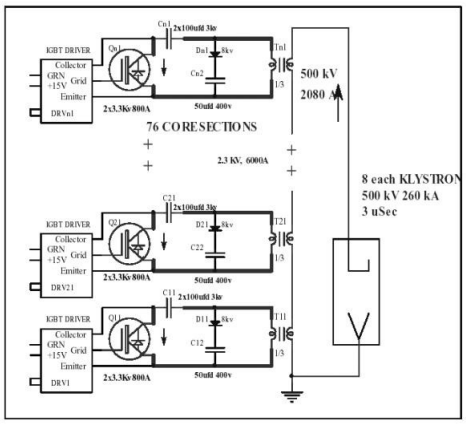

Fig.1. Simplified circuit of the induction modulator

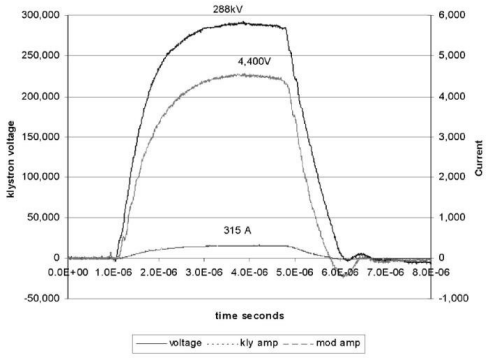

Fig.2. The model preliminary waveform

As the operating parameters of the model were23 kV, 6000 A, then for the test using the klystron such as 5045 (340 kV, 396 A) the transformer 1/15 was used. The model has operated to demonstrate that the concept was workable. Preliminary results are shown in fig.2.

One more solid-state induction modulator proposed by J.A. Watson, E.G. Cook, Y.J. [2] for high-speed kicker, is executed on MOSFET. It has the same structure as the above-described modulator. The modulator provides a nominal 18 kV pulse +/-, rise times of the order of 10 nS, and can be configured for either positive or negative polarity.

The hybrid modulator offered by M. Kempkes DTI [3], has three major components: 80 κV, 100 kW switching power supply, 80 κV, 3500 A solid-state switch (Fig.3), and 6.5:1 pulse transformer. The hybrid

modulator can drive 1 or 2 klystrons and it is currently in testing at DTI.

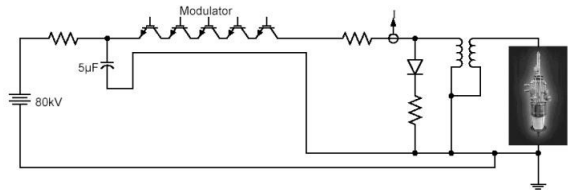

Fig.3 NLC hybrid modulator schematic

The circuit developed by the Japanese for Japan Linear Collider (JLC) is of interest [4]. The klystron modulator for the JLC is required to produce a 500 kV, 530 A, 1.5 μs flat-top pulse to drive a pair of 75 MW klystrons. This modulator consists of two parallel modulators units, each driving the primary winding of the transformer (Fig.4). The JLC hybrid modulator uses multiple individual solid-state modulators (cell -modulators), which are stacked in the voltage-adder configuration and a 1:5 primary split pulse transformer. Each of cell-modulators is direct switching modulator, which is capable of generating 2 kV pulse at 2650 A.

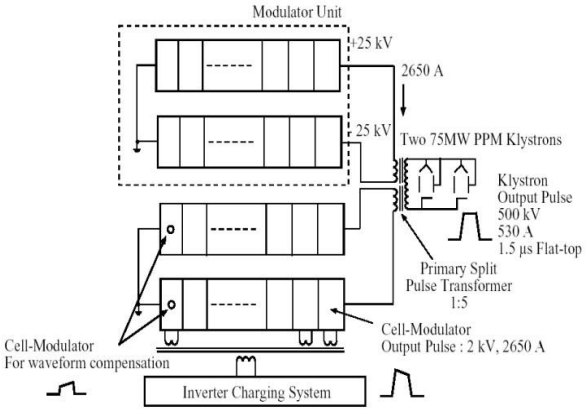

Fig.4. The circuits of JLC modulator

Some cell-modulators are used as a waveform control modulator to obtain an output waveform with a wide flat-top.

The tests of the modulator model consisting of 10 cells were carried out. Design parameters of such modulator 20 kV, 2.7 kA, pulse duration 3 μs, pulse repetition rate 5 Hz.

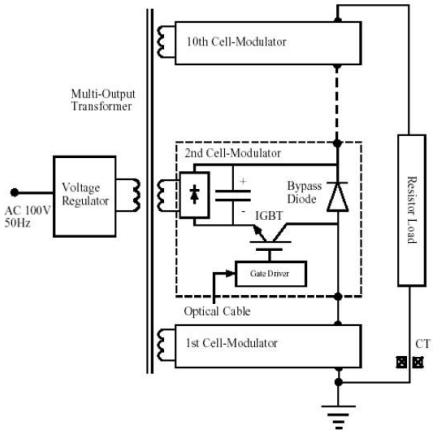

Fig.5. The circuits tested modulator

The modulator was tested at 5,2 Ω resistor load. A pulse with a peak voltage of 17 kV, a peak current of 2890 A, a rise time of 770 ns and a fall time of 580 ns was successfully generated.

The special attention deserves the modulator with fractional-turn primary winding executed by CREWSON Eng [5]. Its feature is that unlike some other solid-state modulators, no semiconductor switches are placed in series in this system fig.7. The dc voltage charges the capacities up to 1 kV. And the key drives to a primary winding of the 1:100 transformer. Such high step-up ratio of transformation is achieved at the expense of the special design of the transformer (use fractional-turn primary winding).

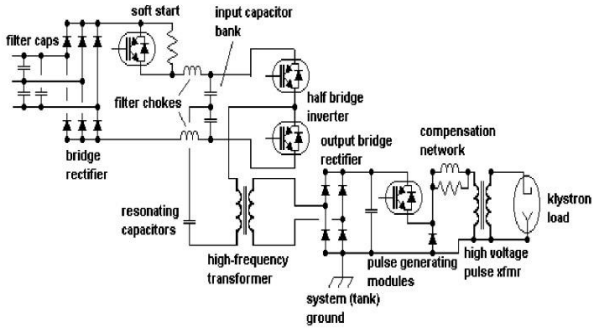

Fig.6. Simplified circuit modulator with a fractional-turn primary winding

It consists from 2 single turn of primary which have been reeled - up on different cores, and the secondary winding consisting of 50 coils, covers both these of the core. In result factor of transformation makes 1:100.

3. MODULATORS WITHOUT TRANSFORMER

The 500 kV hard switch modulator is offered by M. Kempkes, DTI Inc [3].

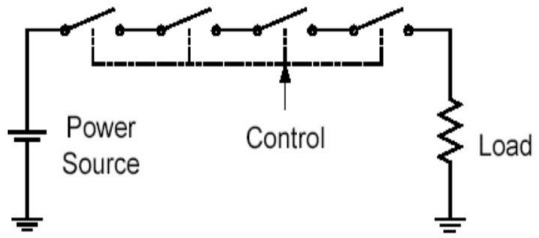

Fig.7. The simplified circuit of 500 kV hard switch modulator

Basic elements of the modulator are: 500 kV source dc voltage, switch 500 kV and current 2120 A. It provides the good form of a pulse, but one has the highest degree of risk failure of switch elements. The efficiency of such modulator is expected about 90%.

The Marx bank system is offered M. Kempkes, DTI Inc [3]. It provides the best pulse waveform, but also has a high probability of failure of elements of the switchboard. Efficiency of this modulator is about 90%.

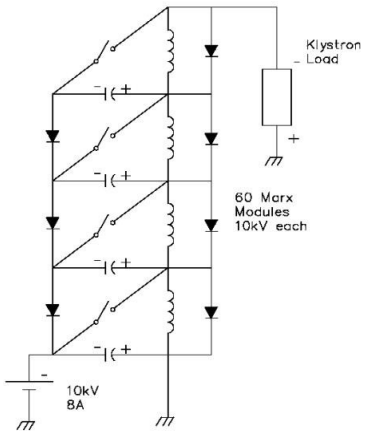

Fig.8. Marx bank system

The modulator with a PFN and thyristor switch is offered by APP, C. Glidden. In this modulator the replacement thyratrone by high-voltage solid-state thyristor with the high di/dt is supposed. The switch module consists of 10 kV modules connected in series; each of them in turn consists of 3 thyristors connected in series with an operating voltage 5kV. The tests of the module with parameters 10 kV, 6 кА on 3 μs PFN with voltage of a charge 30 kV were carried out. The tests have shown an opportunity of application of such modules as switchboards for high-voltage modulators.

In table the parameters of various types of modulators are given.

The comparative table

Authors	U_{out}, kV	I_{out}, kA	t_{rise}/t_{fall}, ns	Pulse duration μs	Repetition rate, Hz	Efficiency, %	A number of driving klystrons
R.L. Cassel & Co. SLAC	500	2,08	<200	1,5	120	>75	8
M.Kempkes & Co., DTI	500	0,53	-	3,2	180	~80	1 or 2
JLC	500	0,53	-	1,5	150	70	1 or 2
CLW	140	0,09	<200	3...10	0...300	~80	1
M.Kempkes & Co., DTI	500	2,12	<200	3,2	-	~90	8
M.Kempkes & Co., DTI	500	0,265	<200	3,2	-	~90	1 or 2

CONCLUSIONS

The construction of modulators on the basis of solid-state elements such as IGBT requires a finding of the compromise between the construction cost, operational cost (efficiency), reliability (probability of failures).

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ВЫСОКОВОЛЬТНЫЕ МОДУЛЯТОРЫ ДЛЯ УСКОРИТЕЛЕЙ НА ОСНОВЕ ТВЕРДОТЕЛЬНЫХ ЭЛЕМЕНТОВ

В.И. Белоглазов, Л.С. Довбуш, В.С. Демин, А.И. Косой, Ю.Д. Тур, С.М. Шкирида

Приводятся данные по разработке и созданию высоковольтных (ВВ) импульсных модуляторов для ускорителей с использованием биполярных транзисторов с изолированным затвором IGBT и запираемых тиристоров со встроенным блоком управления типа IGCT. Проводится сравнительный анализ основных характеристик, таких как КПД формирования, надежность, стоимость, для стандартных модуляторов и полупроводниковых ВВ источников с различной топологией схем.

ВИСОКОВОЛЬТНІ МОДУЛЯТОРИ ДЛЯ ПРИСКОРЮВАЧІВ НА ОСНОВІ ТВЕРДОТІЛЬНИХ ЕЛЕМЕНТІВ

В.І. Белоглазов, Л.С. Довбуш, В.С. Дьомін, А.І. Косою, Ю.Д. Тур, С.М. Шкирида

Наводяться дані по розробці і створенню високовольтних (ВВ) імпульсних модуляторів для прискорювачів з використанням біполярних транзисторів з ізольованим затвором IGBT і тиристорів, що замикаються, з убудованим блоком керування типу IGCT. Проводиться порівняльний аналіз основних характеристик, таких як ККД формування, надійність, вартість, для стандартних модуляторів і напівпровідникових ВВ джерел з різною топологією схем.