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<https://doi.org/10.48081/JBMZ50037>***V. Melnikov¹, O. Talipov², Yu. Kibartene³**^{1,2,3}Toraighyrov University,

Republic of Kazakhstan, Pavlodar

EVALUATING THE POSSIBILITY OF APPLYING CONTROLLED COMPENSATION SYSTEMS TO IMPROVE EFFICIENCY IN ELECTRIC GRIDS

The paper considers issues of increasing efficiency of multilevel power converter based on IGCT and IGBT modules to improve energy performance by compensating reactive power in electric networks. By the example of a local power grid using SEMIS SimulationTool design tool the results of calculations of variants of multilevel converters with IGCT and IGBT are presented. The study of possibilities to increase the efficiency of multilevel power converters (MPE) for reactive power compensation (RPC) in local electrical networks (LES) on the basis of plenipotentiary controlled semiconductor cells is of particular interest, because the efficiency of network operation is insufficient, especially in changing load modes with large electric power losses (PEM). And from these positions, one of the most effective tools are fast controlled (PFC) systems. For this purpose, research has been carried out to obtain the best results. Used in calculations tool and methodology are certified software products and algorithms of ABB-SEMIS Simulation Tool computer design.

Keywords: electric power transmission, efficiency, losses, reactive power, compensation, IGCT, IGBT, power module.

Introduction

The study of possibilities to increase the efficiency of multilevel power converters (MPE) for reactive power compensation (RPC) in local electrical networks (LES) on the basis of plenipotentiary controlled semiconductor cells is of particular interest, because the efficiency of network operation is insufficient, especially in changing load modes with large electric power losses (PEM). And from these positions, one of the most effective tools are fast controlled (PFC) systems. For this purpose, research has been carried out to obtain the best results. Used in calculations tool and methodology are certified software products and

algorithms of ABB-SEMIS Simulation Tool computer design. The relative error of calculations for different power modules ranges from 5.7×10^{-8} to 1.08×10^{-7} which is a good value. A study of parameters of efficiency of the power part of MPE for PFC on the basis of power transistor and thyristor PM for LES of voltage level 6 kV is carried out. For other voltage levels, for example, 10-20 kV and above, the methodology of obtaining adequate results is similar to the considered. Appearance of schemes, graphic, tabular and other illustrating information is presented in the form corresponding to the original – software development company and technical description for application of equipment, technologies and suppliers of technologically developed countries.

Materials and methods

The calculation scheme of the power part of RPCS based on the power transistor IGBT bridge, the interface of input and set parameters and the view of the digital design output fragment in the form of calculation curves and tables are shown in Figure 1. The column (center) describes the initial data for research (marked in red and yellow) and the recommended set of types and basic parameters of power transistors and diodes (marked in lilac), acceptable for the accepted design version of the initial data of the fast-acting RPCS.

Figure 1 – Schematic diagram of the RPCS power section based on a full-force transistor IGBT bridge (left); interface of input and set parameters (center) and a fragment output view of the digital design results (right)

To conduct comparative analysis of RPCS, as shown in Fig. 2, the following initial data were taken: ambient temperature – 40°C; number of power transistor cells in phase – 5; system frequency of electric current – 50 Hz; switching frequency of power gates of full bridge – 269,23 Hz; modulation index – 0,8; linear voltage of converter – 6,0 kV; design PM – 9,0 Mvar; type of converter PM – capacitive; thermal resistance of IGBT – 0,02 K/W. IGBT module type adopted for research – HiPak; IGBT operating voltage – 3.3 kV; IGBT module configuration – Single IGBT. The results of calculations of electrical parameters for the most severe case of steady-state electrical full load are shown as curves in Figure 3 (left) from top to bottom: inverter phase voltages and currents; inverter AC side voltages and currents; average voltage value of compensating capacity type IGBT module; below, respectively: losses of IGBT1 and reverse diode D1 in conducting state and in switching mode; heating temperatures of power semiconductor components IGBT1 and D1 for 6 parameters.

Figure 2 – Calculation results for the specified 6 variants of IGBT modules

The following HiPak IGBT modules were used for the calculations. Their appearance, main data and possible wiring diagrams are shown in Figure 3. All HiPak 3.3 kV IGBT modules are optimized to minimize electric energy losses and have very «soft» switching characteristics together with the integrated reverse diode. They differ in current: 5SHA 1200N330400 HiPak IGBT module – 1200A; 5SNA 1500E330305 – 1500A; 5SNA 1800E330400 – 1800A.

Full parameters and characteristics of these modules are given in the technical description of the equipment supplier, and detailed calculation results for these IGBT modules are shown in Figure 4.

Thus, having considered 6 options for the use of power semiconductor components – IGBT1 ... IGBT4 and power reverse diodes of full bridge, we note, in general, the high efficiency of the adopted scheme. At the same time, the

calculated total losses for various options are from 0.63 % to 0.98 %, or in nominal units from 56.49 kW to 88.53 kW of electrical power. Characteristics in the form of design curves and design parameters for the variant of RPCS with the lowest losses when using HiPak IGBT module are shown in Figure 5.

Figure 5 – Calculation curves (left) and calculated parameters for the RPCS variant with the lowest loss when using a HiPak IGBT module

Assessment of annual losses of energy under the condition of constant year-round operation – 8760 hours/year, with full steady load, by options: for the option of minimum converter losses of 56.49 kW, it will make 494852.4 kWh. At cost of «commodity» product – electric energy on a selling tariff of 0,0023 \$/kWh cost of annual losses for the best of considered variants will make \$11156.43 for one connection.

For comparison further a research of parameters of efficiency of power part of MPE for RPC based on full thyristor controlled cells is carried out. The design diagram of the power part of REM on the basis of a power thyristor IGCT bridge, the interface of input and set parameters and the view of a fragment of digital design results output in the form of design curves and tables are shown in Fig. 6. The circuit is multimodular, the PM contains a compensating capacitance «tied» by semiconductor controlled components – thyristors with reverse-connected diodes. The computational «star» circuit in Figure 6 (left) contains 5 PM in each branch. The branches are symmetrical and form a three-phase electrical system with the possibility of separate regulation of electrical parameters in each phase. Thyristors IGCT1.... identical in parameters are used in each PM IGCT4 and reverse diodes D1...D4. Thermal resistance of IGCT is 0,03K/W, other parameters correspond

to those given in Fig. 1 for comparative researches. The types of IGCTs adopted for research are reverse and asymmetric conductivity; operating voltage is 4.5 kV.

Figure 6 – Calculation diagram of the RPCS power part based on the IGCT bridge (left); interface of input and set parameters (center) and the output fragment view of the digital design results (right)

Calculation results are shown as curves in Figure 6, from top to bottom on the right: inverter phase voltages and currents; inverter AC side voltages and currents; average voltage value of the IGCT module compensating capacitance; below, respectively: IGCT and reverse diode D losses in conducting state and in switching mode; heating temperatures of IGCT and D for 9 variants of their parameters.

Parameters and main characteristics of pre-selected power components for calculation of IGCT RPCS electrical circuit variants are shown in Figure 7. The following recommended variants are considered: 5SHX36L4521, 5SHX36L4520 and 5SHX26L4520.

Figure 7 – Basic data and appearance of the PM selected for preliminary calculations

To calculate the variant preliminarily accepted from those recommended by the company-supplier full-featured thyristor module, controlled by input, reverse conductivity, 5SHX36L4521 type with parameters: voltage – 4500V, current – 3600A; pulse current – 20000A; voltage drop in open state – 1,24V; internal

resistance at nominal parameters – 0,51 mOhm; direct current voltage – 2800V. Module is intended for work in electric circuits of direct and alternating voltage. It contains an RC-IGCT power semiconductor component in the form of a fully controlled thyristor and reverse diode, as well as a control component, as shown in Figure 8.

Fig. 13 Block diagram

Figure 8 – Schematic diagram of integrated module with fully input controlled thyristor, reverse diode and control unit

Results and discussion

To calculate the version of power circuit preliminarily taken from among those recommended by the company-supplier IGCT module, controlled by input, reverse conductivity, type 5SHX36L4520: voltage – 4500V; current – 3600A; pulse current 15000A; open voltage drop – 1,59V; internal resistance – 0,74 mOhm; DC voltage – 2800V. Designed for operation in DC or AC voltage circuits and recommended for use with the above initial data. The module contains an RC-GCT power semiconductor component in the form of a fully controlled IGCT and reverse diode, as well as a control component; the schematic is shown in Figure 8.

By analogy, we have considered 9 options for using power semiconductor components – power cells with IGCTs, we note, in general, their high efficiency. Estimated total PEM are from 0.89 % to 0.98 % or from 79.69kW to 88.31kW. For the minimum PEM option, the annual PEM cost is \$ 15477.95; for the maximum PEM option, it is \$ 17152.16. The worst case with IGCT and the best case with IGBT gives the difference, which at a lifetime of 25 years and an optimistic scenario of stable cost of electrical energy would be \$ 154507.36; the best case with IGCT and the best case with IGBT under the same conditions would result in \$ 112651.5.

Conclusions

In conclusion, we note, in general, the high computational efficiency of the schemes under consideration. The calculated total PEM with IGBT modules is 0.63 % for the best variant; the use of fully controlled IGCT modules gives the minimum level of PEM – 0.89 %.

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*В. Мельников¹, О. Талипов², Ю. Кибартене³

^{1,2,3}Торайгыров университеті,

Қазақстан Республикасы, Павлодар қ.

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ЭЛЕКТР ЖЕЛІЛЕРІНДЕ ТИІМДІЛІКТІ АРТТЫРУ ҮШІН РЕТТЕЛЕТІН ӨТЕМАҚЫ ЖҮЙЕЛЕРІН ҚОЛДАНУ МҮМКІНДІГІН БАҒАЛАУ

Мақалада электр желілеріндегі реактивті қуатты өтеу арқылы энергия көрсеткіштерін жақсарту үшін IGCT және IGBT модульдеріне негізделген көп деңгейлі қуат түрлендіргішінің тиімділігін арттыру мәселелері қарастырылады. SEMIS SimulationTool жобалау құралын қолдана отырып, жергілікті электр желісінің мысалында IGCT және IGBT бар көп деңгейлі түрлендіргіштердің нұсқаларын есептеу нәтижелері келтірілген. Өкілетті басқаруы бар жартылай өткізгіш элементтер негізінде жергілікті электр желілерінде (ЛЭС) реактивті қуатты (RPC) өтеу үшін көп деңгейлі қуат түрлендіргіштерінің (MPE) тиімділігін арттыру мүмкіндіктерін зерттеу ерекше қызығушылық тудырады, өйткені желі жұмысының тиімділігі жеткіліксіз, әсіресе электр энергиясының үлкен шығындарымен (РЕМ) жүктеме режимдері өзгерген кезде. Осы тұрғыдан алғанда, ең тиімді құралдардың бірі – жылдам басқару жүйелері (PFC). Осы мақсатта жақсы нәтиже алу үшін зерттеулер жүргізілді. Құрал мен есептеу әдістемесі сертификатталған бағдарламалық өнімдерді және ABB-SEMI Simulation Tool Компьютерлік жобалау алгоритмдерін қолданады.

Кілтті сөздер: электр қуатын беру, тиімділік, жоғалту, реактивті қуат, өтемақы, IGCT, IGBT, қуат модулі.

*В. Мельников¹, О. Талипов², Ю. Кибартене³

^{1,2,3}Торайгыров университет,

Республика Казахстан, г. Павлодар.

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ОЦЕНКА ВОЗМОЖНОСТИ ПРИМЕНЕНИЯ СИСТЕМ РЕГУЛИРУЕМОЙ КОМПЕНСАЦИИ ДЛЯ ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ В ЭЛЕКТРИЧЕСКИХ СЕТЯХ

В статье рассматриваются вопросы повышения эффективности многоуровневого преобразователя мощности на основе модулей IGBT и IGBT для улучшения энергетических показателей за счет компенсации реактивной мощности в электрических сетях. На примере локальной электросети с использованием инструмента проектирования SEMIS SimulationTool представлены результаты расчетов вариантов многоуровневых преобразователей с IGBT и IGBT. Изучение возможностей повышения эффективности многоуровневых преобразователей мощности (МРЕ) для компенсации реактивной мощности (RPC) в локальных электрических сетях (ЛЭС) на основе полупроводниковых элементов с полномочным управлением представляет особый интерес, поскольку эффективность работы сети недостаточна, особенно при изменении режимов нагрузки с большими потерями электроэнергии (РЕМ). И с этих позиций одним из наиболее эффективных инструментов являются системы быстрого управления (PFC). С этой целью были проведены исследования для получения наилучших результатов. В инструменте и методологии расчетов используются сертифицированные программные продукты и алгоритмы компьютерного проектирования ABB-SEMIS Simulation Tool.

Ключевые слова: передача электроэнергии, КПД, потери, реактивная мощность, компенсация, IGBT, IGBT, силовой модуль.

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