International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 12 (2019), pp. 2683-2686

Ensuring the Quality of Power Supply to Industrial Enterprises Using Universal Power Converters

E.A. Buzoverov[1], A.Y. Varaksin[1,2] and K.K. Denshchikov[1]
[1]Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow, Russia.
[2]Bauman Moscow State Technical University, Moscow, Russia.

Abstract

The issues consider the use of Universal Power Converters (UPC) as an energy storage device, which are the first hybrid energy storage device for high-voltage circuits (10 kV), capable of supporting rated voltage quality for up to 3 seconds. A methodology has been developed for evaluating the technical and economic efficiency of UPC taking into account its design and production features. It is shown that the use of UPC is advisable not only to improve the quality of power supply to industrial enterprises, but also to eliminate interference and distortion in the network that some enterprises create in the process of their operation. The analysis of statistics of emergency power interruptions, leading to damage for various industrial enterprises in the context of Russian regions, is carried out. Based on the analysis of the technical and economic indicators of the use of UPC and the quality of power supply, the total capacity of the UPC market was calculated for the industries in which the use of the device is most effective – petrochemicals, chemical industry and pharmaceuticals.

Keywords: Power Supply, Universal Power Converter, Hybrid Energy Storage Device

I. INTRODUCTION

Currently, an established global trend is the development of Smart Grid technology for national and regional power supply networks, which determines the spasmodic growth of the global market for energy storage systems. It is assumed that over the next ten years the global market for energy storage systems will grow by two orders of magnitude – from USD 0.5 billion to USD 50 billion [1].

One of the most important elements of Smart Grid systems is energy storage systems that allow you to solve the following problems:

- ensuring the quality and reliability of power supply;
- integration of alternative energy systems with traditional power plants;
- energy recovery in electric vehicles;
- partial replacement of generation in the role of power regulatory;
- reduction in the cost of ownership of distributed generation;
- deferred investments in infrastructure by reducing peak load;
- energy supply of isolated areas or areas with a weak network.

The main effect of the use of energy storage systems is to restrain the growth of electricity prices for industrial consumers by increasing the capacity utilization factor, reducing the need for new capacity, as well as reducing energy losses and the cost of network ownership.

The studies and analysis of the conditions for the use of energy storage systems have shown that their main technical characteristics – stored energy, delivered power and discharge time – have limited scalability. A recognized way out of this situation is the use of hybrid technologies and the differentiation of energy storage systems depending on the conditions of their use [2].

So, for example, to ensure the quality of power supply to most end-users of the non-industrial sector, it was proposed to use hybrid systems for energy storage of the kilowatt range based on batteries of batteries and supercapacitors [3], and for industrial enterprises using power supply to the megawatt range, to use hybrid energy storage systems based on batteries of supercapacitors and static converters [4].

II. UNIVERSAL POWER CONVERTER

Universal Electric Power Converter (UPC) is designed for:

- reactive power compensation;
- active filtering of the upper harmonics of the load current;
- suppression of harmonic voltage distortion at the connection point;
- balancing the network voltage;
- generation of active power due to the energy storage system during short-term power interruptions.

Thus, UPC is the first industrial hybrid energy storage device for high-voltage circuits (10 kV) capable of supporting up to 3 seconds the rated voltage during a power outage, which predetermines its competitiveness in the market.

UPC consists of a voltage converter (VC), an energy storage device (ES) and a control system (CS) as shown in Fig. 1. The voltage converter performs the functions of the voltage regulator of the network, balancing the voltage of the network, actively filtering the harmonic components of voltage and current, as well as the functions of a rectifier and inverter for servicing the energy storage device. The energy storage device is designed for short-term output of active power in the event of a power failure. The control system manages and protects the above mentioned components.

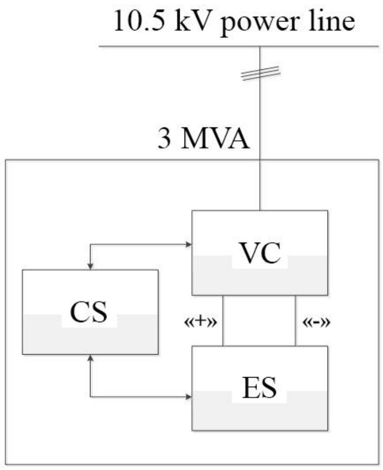

Fig. 1. Schematic diagram of the UPC

The main element in the energy storage is a battery of supercapacitors [5]. The required storage capacity is achieved through the use of original type-setting supercapacitors of our own design, several times cheaper and having much (4 times) more power than the foreign-made supercapacitor battery on the market.

The use of UPC allows to:

- reduce the number of shutdowns of three-phase synchronous and asynchronous motors in the reverse sequence caused by an increased level of voltage unbalance;
- prevent accelerated wear of equipment caused by an increased level of upper harmonics;
- provide voltage stabilization in the presence of abruptly variable loads;
- reduce damage from disruptions of continuous technological production caused by interruption of power supply.
- Thus, the UPC occupies an intermediate position between devices that can only improve the quality of electricity and uninterruptible power systems.

The prospects of UPC in the market by segments of potentially interested consumers will be evaluated further through economic calculation.

III. FEASIBILITY STUDY ON THE USE OF UPC

The calculations of the effectiveness of the application of UPC are based on similar methods previously developed to analyze the economic efficiency of traditional technologies for generating electricity [6], taking into account the design and production features of the analyzed device.

III.I Cost of Ownership Calculation

According to preliminary estimates of potential manufacturers, the cost of UPC in serial production will be $C_{prod} = 190$ USD / kVA.

Given the design, installation and commissioning works, the cost of the UPC for the customer will not exceed $C_{cap} = 300$ USD / kVA.

The operational costs of servicing a UPC are estimated at 5% of its cost $C_{opex} = 15$ USD / kVA / year.

Thus, the present annual cost of ownership of the UPC, taking into account the cost of invested capital, is USD / kVA / year:

$$C = C_{cap} \cdot CRF + C_{opex}, \qquad (1)$$

where CRF is the return on equity ratio [7]:

$$CRF = \frac{d}{1-(1+d)^{-n}}, \qquad (2)$$

where d is the discount rate, $d = 15\%$; n is the UPC lifespan, $n = 25$ years.

According to the results of the calculation, the present annual cost of ownership of the UPC will be $C = 61$ USD / kVA / year.

III.II Calculation of Damage from Interruptions

The effect of the use of UPC is determined mainly by the exclusion of damage from emergency situations, which can be assessed in accordance with [7]. The specific damage caused by interruption of power supply to industrial enterprises (C_{har}, USD / kW) has a very wide spread, but primarily depends on the profile and category of enterprises and ranges from 0.05 for production of ferroalloys to 200.63 for petrochemicals.

The number of interruptions in the power supply of industrial enterprises can be estimated by analyzing the annual accident statistics in industrial power supply networks [8]. In accordance with this information, the number of emergency shutdowns for one year of lines with voltage of 35 kV and 110 kV supplying industrial enterprises is in the ranges (3 - 216) for 35 kV and (6 - 518) for 110 kV.

Based on statistical data [8], the average ratio of power interruptions due to the fault of power supply networks to interruptions that occurred in the circuits of the enterprise itself is 1:4. However, not every short-term interruption of power supply causes emergency shutdowns of production equipment. The likelihood of disconnecting the equipment of the enterprise during interruption of power supply is estimated at 10%.

Based on the given initial data, the total load u, MVA / year, of the lines of 35 kV and 110 kV was calculated, subjected to blackouts during the year in each of the power supply regions:

$$u = pk\,(a_1 h_1 + a_2 h_2)\,, \qquad (3)$$

where p is the probability of shutdown of the enterprise equipment during interruption of power supply, $p = 10\%$; k is the conversion factor of power interruptions to interruptions that occurred in the enterprise circuits, $k = 0.25$; a_1 and a_2 are the maximum practical load of the lines, respectively, 35 kV and 110 kV: $a_1 = 12.5$ MVA; $a_2 = 37.5$ MVA; h_1 and h_2 are the annual number of power outages for consumers of 35 kV and 110 kV lines, respectively, adopted for each region according to statistical data.

Knowing the installed capacity of the energy sources of the considered voltage range in the region, we can estimate the probability of disconnecting the corresponding consumers P in the form:

$$P = \frac{u}{U}\,, \quad (4)$$

where U is the summarized capacity of 35 kV and 110 kV power sources installed in the region, MVA.

Thus, for each type of enterprise in a particular region, the potential annual damage from interruptions C_{har}, USD / kVA / year can be estimated:

$$C_{har} = \frac{c_{har} P}{\cos\varphi}\,, \qquad (5)$$

where c_{har} is the specific damage from interruption of power supply, USD / kW; $\cos\varphi$ is the power factor, $\cos\varphi = 0.8$.

III.III Potential Capacity of the UPC Market in Context of Russian Industries

Those enterprises for which the potential annual damage from outages exceeds the present annual cost of ownership of the UPC (condition $C_{har} > C$ is met) may be interested in acquiring it. Territorial-industrial units for which the use of the UPC is considered unprofitable (condition $C_{har} > C$ is not met) was not considered in the subsequent part of the studies.

Data on electricity consumption by industrial sectors of Russia [9] made it possible to calculate the capacities of various types of production by region, N, MVA:

$$N = \frac{E}{T\cos\varphi}\,, \qquad (6)$$

where E is annual electricity consumption by industrial sectors of Russia, MW h / year, is taken according to the tables of the State Statistics Committee, given in [9]; T is the annual number of hours an enterprise uses installed capacity, T = 5000 hours.

Then the capacity of the UPC market for interested industries and regions of Russia is M, thousand USD / year:

$$M = N\,C_{prod}\,. \qquad (7)$$

The same economic indicator, expressed in the required number of devices, is m, pcs.:

$$m = \frac{N}{n}\,, \quad (8)$$

where n is the design power of the UPC, MVA.

Based on the analysis of annual electricity consumption by industrial enterprises in the regions of Russia, it is possible to determine the capacity of the UPC market by the main interested industries (Fig. 2).

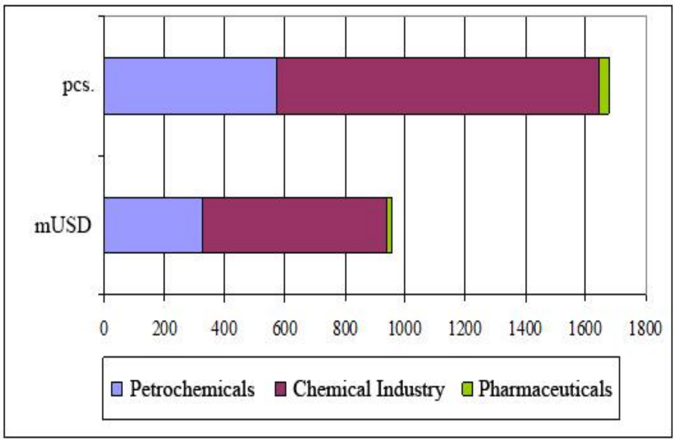

Fig. 2. The total capacity of the UPC market in the regions of Russia

Additional segments of the UPC market to compensate for the negative impact of the consumer on the network.

The main direction of UPC sales will be consumers who seek to improve the quality of electric energy received from the network and reduce the damage from power outages. But at the same time, there is a fairly significant cluster of enterprises that have powerful electrical equipment, which themselves are sources of interference and distortion in the network.

An example of electrical equipment that creates such interference can be electric arc furnaces installed in steel mills, which during operation can create upper harmonics. Railway rolling stock with an electric drive can also pose a significant problem for nearby consumers; its operation can cause an asymmetry of phase voltage and currents in the network.

These problems are most acute in autonomous energy systems and long-distance networks, in which the effect of reducing equipment on the quality of electricity on nearby consumers is greatest.

It should also be noted that the use of UPC in the enterprises themselves, having equipment that degrades the quality of electricity, is also able to bring them a significant economic effect. It is known that the use of a static VAR compensator can reduce metal smelting time by 20%, as well as increase the efficiency of an arc furnace and reduce the consumption of electrodes and lining. However, due to the use of a voltage converter type UPC, a similar result is achieved with a lower installed power. This is due to the fact that the UPC allows the formation of a negative sequence current up to 60% of the current in a direct sequence, while for STK this indicator does not exceed 25%.

IV. CONCLUSIONS

There has been developed a methodology for evaluating the technical and economic efficiency of the application of UPC, taking into account its design and production features.

It is shown that the use of UPC is advisable not only to improve the quality of power supply to industrial enterprises, but also to eliminate interference and distortion in the network that some enterprises create in the process of their operation.

The analysis of statistics of emergency power interruptions, leading to damage for various industrial enterprises in the context of Russian regions, is carried out.

Based on the analysis of technical and economic indicators of the use of UPC and the quality of power supply, the total capacity of the UPC market was calculated by industries in which the use of the device is most effective – petrochemicals, chemical industry and pharmaceuticals.

ACKNOWLEDGEMENTS

This work was financially supported by the Ministry of Education and Science of Russia (agreement No. 14.604.21.0178, unique identifier of project is RFMEFI60417X0178).

REFERENCES

[1] Annual Installed Energy Storage Power Capacity, Top Countries 2015 – 2025. Navigant Research Smart Grid, 2015.

[2] Denshchikov K K, Varaksin A Yu. Hybrid Technologies for Creating Energy Accumulation Systems // International Scientific Journal for Alternative Energy and Ecology. 2019;(07–09):106–115.

[3] Denschikov K K, Zhuk A Z , Fortov V E, Sheindlin A E. Hybrid Electric Energy Storage. Energy: Economics, Engineering, Ecology. 2015;(2):2–10.

[4] Denshikov K K, Varaksin A Yu. Hybrid Energy Storage Device Using Static VAR Compensators and Supercapacitors to Ensure the Quality of Power Supply to Consumers in the Oil and Gas Industry. Collection of Scientific Papers of the Eurasian Scientific Association. 2017;(12): 40–42.

[5] Denshchikov K K. Stacked Supercapacitors of New Generation // International Scientific Journal for Alternative Energy and Ecology. 2019;(07–09):97–105.

[6] Zhuk A Z, Zeigarnik Yu A, Buzoverov E A, Sheindlin A E, Kucherov Yu N. Feasibility Study of Peak Power Supply Technologies. Energy: Economics, Engineering, Ecology. 2016; (9): 12–19.

[7] Ereev S, Patel M. Standardized Cost Estimation for New Technologies (SCENT) – Methodology and Tools. Journal of Business Chemistry. 2012; (9): 31–48.

[8] Reliability Analysis of Internal and External Power Supply. URL: http://www.mosvodokanal.ru/upload/iblock/content/bf3/analiz-nadezhnosti-vnutrennego-i-vneshnego-elektrosnabzheniya-2010.PDF.

[9] Electricity Consumption by Industrial Organizations. EMISS site. State Statistics. URL: https://www.fedstat.ru/indicator/58653.