BES INSTALLATION IN LOCAL ENERGY MARKET

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Abstract - This paper refers to the scientific project "Economic and technical analysis of battery energy storage usage in the local energy market". The main objective of the project is to consider technical and economic aspects of BES usage in the Polish power distribution network operating in the competitive conditions. Research is focused on analysis of possibilities of energy storage device usage for load levelling and its influence on a quality of electrical energy. The first part of the paper presents key-information about purpose, range of research and expected results of this project. In the second section of the paper initial outputs of the laboratory tests of a battery are submitted. Basic information about a conversion and control system is also presented. It is expected that the result of the project and experience from renewable sources operation in Polish distribution system allow to work out a new formula of local sustainable systems.

Keywords - battery energy storage, power distribution network, local energy market, load profile

I. INTRODUCTION

Application of competitive rules in the energy market is one of the key-problems of Polish energy sector transformation. Planned changes in a structure and new regulations should meet basic criteria of a fully and properly developed (balanced) energy market, e.g. safety, quality of electrical energy and service. Taking into accounts present and future conditions of the energy sector specific activity, power companies should intensify any actions connected with load planning and management.

In the competitive market, costs of the energy production, transmission and distribution will be the main criterion for choosing a development (expansion) scenario by the power utilities. According to the results of nation-wide research works it seems that battery energy storage could be one of the possible options answering these requirements. In addition, the usage of energy storage devices is one of the relatively new conceptions considered in the process of power sector planning and could be an alternative for traditional solutions.

The usage of hydro pumped storage power stations is a prior method for load levelling in the wholesale market level in Polish energy sector. Valley filling and peak load clipping on the level of local energy markets could be achieved mainly through traditional methods of load control. Polish energy sector did not attempt to apply energy storage devices for load management so far. It is observed that the importance of energy storage devices from load levelling perspective in the distribution network still increases. International feasibility studies and researches show that about 1900 MW could be located in BES in German power network. According to EPRI and ILZO[1] study, the future needs of energy storage in theUSA could achieve even 10 GW [2]. In addition because of technical, economical and environmental benefits derived from that BES, numerous peak-clipping battery facilities on end-user level are expected to be built in the close future.

Therefore it seems that researches connected with this issue could be purposeful and attractive from scientific and commercial point of view.

This paper is linked with the scientific project "Economic and technical analysis of battery energy storage usage in the local energy market", which is carried out by Bialystok Technical University (BTU) research team. This paper aims at introducing key-information about major goals, range of research and expected results of this project. An idea of a future research work connected with application of BES for separated part of local energy market is also presented in this paper.

II. REASONS AND BENEFITS OF BES USAGE IN POWER NETWORK

Reasons and potential benefits of BES usage in power distribution network are presented from load curve shaping perspective. Thanks to a peak load clipping and a load levelling it is possible to change a structure of wholesale purchase and retail sales. Apart from a peak clipping and a load levelling BES may also the fulfil other important function in the power network, e.g. instantaneous reserve, emergency supply and frequency control. Due to the range of the research the third possibility is not considered in the paper.

Other important benefit coming from BES usage in distribution system is a possibility of regulation of the output from a wind power station. The aspect of a potential association of renewable sources and storage systems seemed to be one of the prior tasks in the process of sustainable development of energy sector.

Effects of load curve shaping could bring power utilities or even end-users measurable benefits:

- load levelling benefits,
- supply side benefits.

[1] International organisation of lead and zinc producers.

The first group of benefits results from changes in energy sales. BES can be charged during the off-peak period with lower energy cost and then could be discharged during peak load period when the energy and power cost is higher. This case of BES usage in the power distribution network could be illustrated by figure 1. Load profile given in that graph is averaging winter profile of load, which has been measured on the substation level (15/0,4kV). It is worth noticing that residential customers are supplied from those substations. Taking into account policy of the local utility, load profiling could be strongly recommended in this case. Due to unfavourable, from utility perspective, shape of load curve majority of DSM programmes are designed and applied in this sector of end users [3].

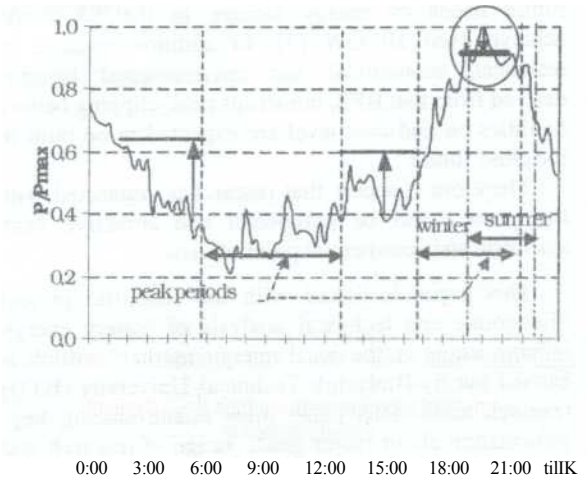

Figure 1. Load shifting effect caused by BES usage (schematic figure)

Thanks to procedure of load levelling a direct tariff profit could be obtained. In addition the usage of BES has a favourable, from utilities and customer point of view effect on:

- reduction of energy losses in a distribution system by a better control of power flow during the peak period,
- reduction of power failure costs (costs of an undelivered energy),
- increasing the reliability of distribution power system.

From the energy system (supply-side) perspective, BES allows to:

- reduce capacity of supply side (avoided or postponed capital costs),
- reduce environmental costs (environmental protection charges),
- receive environmental benefits from customer and society point of view.

These reasons and potential benefits confirmed purposefulness of battery energy storage usage for load management [1,2].

Considering BES as a part of a dispersed generation system, BES has special characteristics, which could very useful in that case, e.g.: modularity and portability. Thanks to these features BES units could be relocated and developed. In addition the risk of investment in this situation could be significantly reduced.

III. PROJECT OVERVIEW

The main objective of the project is to consider technical and economic aspects of BES usage in the power distribution network. The research is focused on analysis of possibilities of energy storage device usage for load levelling and its influence on a quality of electrical energy and on a distribution system operating in the competitive conditions.

From a technical side project is focused on preparation of a complete control and a conversion system, which would be able to fulfil quality requirements. Potential economic benefits of BES usage in the distribution network, which would be estimated, are connected with the following aspects:

- load shifting,
- energy quality.

The first group includes a benefit of peak load shifting (direct tariff benefit) and profit coming from postponing a capital expenditure on supply side (modernisation of power distribution network). On the other hand costs/benefits of an influence of BES on electrical energy should be taken into consideration.

Due to a national range of the project, peculiarity of Polish local energy markets has been taken into consideration in that study.

The research is carried out by the team from Faculty of Electrical Engineering and Faculty of Management. Thanks to an international scientific co-operation between BTU and Magdeburg and Stuttgart University research teams from those academic centres also support surveys. The presented project includes results of Joint European Project "Intelligent Computation and Simulation in Planning and Operation of Power System Taking into Account Energy Storage". It was prepared and led by an international consortium from six Western and Eastern countries in the scope of INCO-Copernicus programme. It should be stressed that Bialystok Technical University was a main partner in that project.

It is worth noticing that Bialystok Technical University, as the first scientific centre in Poland, has started researches with an experimental battery energy storage installation. The surveys are carried out within the confines of scientific project sponsored by the State Committee for Scientific Research.

The results of this project could be treated as an incentive for future researches and potential BES installation in power network. Thanks to BES installation the power utilities' objectives connected with load profiling could be achieved. Taking into account transformation of Polish energy market, energy storage options could be interesting for its participants from a technical and economic point of view.

IV. BES EXPERIMENTAL INSTALLATION

All measurements and simulations are carried out with the experimental battery storage installation. Those appliances have been donated to Bialystok Technical University by Hagen Baterrie AG within the scope of international scientific co-operation.

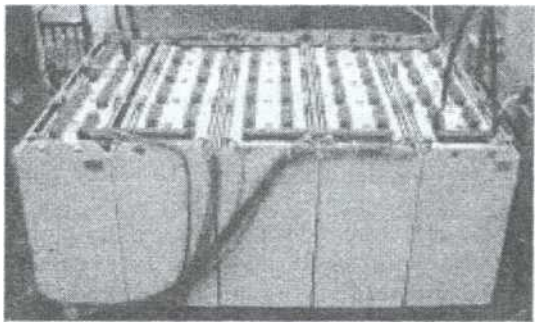

Figure 2. Installation of energy storage device in **BTU**

The experimental BES installation includes 10OCSV1000 type battery made in valve-regulated lead-acid technology (Figure 2). The nation-wide experiences and tests indicate that VRLA battery technology offers a relatively low start-up cost of battery (about 250USD/kW) and more comfortable maintenance comparing to vented lead acid batteries. Life expectancy of VRLA batteries, according to warranty time, is estimated at ten years (on average) [4].

The tested battery consists of four modules including five cells and one module with four cells. Other parameters of the battery are given in Table 1.

Table 1. Basic parameters of battery

Type of parameter	Value/specific
Capacity of battery:	**1000 Ah, 5 hours**
Voltage of module:	**10V(8V)**
Number of all cells:	**24**
Voltage of one cell:	**U_C=2V**
Voltage of battery:	**U_N=48 V**
Module current:	**I^IOOOA**

BES installation includes also:

- a power transformer (aerial; 380/59 V; voltage ratio ŭ = 6,45; connection symbol of a transformer Dd 0),
- a line-commutated converter,
- a control and monitoring system,
- a protection system (overcurrent protection).

The line-commutated converter consists of two 6-pulse bridges. This technology is very well known and the quality of that a kind of solution is proven. It seems that the biggest problem with these converters usage in the power distribution is power quality. In order to minimise the negative influence of BES on distribution network an active filter has been design and built. Thanks to this filter it may be possible to compensate reactive power and reduce a level of total harmonic distortion. More information about that filter is given in the following part of the paper.

The control and monitoring system allow to measure current, voltage and temperature. The third parameter is especially important because of life expectancy of the battery. The cooling system operates according to hysteresis characteristic in a closed cycle.

The tested BES is placed in the laboratory of BTU Faculty of Electrical Engineering. BES is supplied from a laboratory low voltage network.

V. RANGE AND MAIN OUTPUTS OF RESEARCH

The experimental BES installation is considered as a specific application for load peak shaving. Some planned activities would be taken in the selected parts of the local energy market. Therefore in order to estimate technical and economic effects of BES usage from that perspective it is necessary to perform first of all measurements of charge and discharge process. Taking into account law regulations and requirements of the energy markets, the analysis of BES influence on distribution system is also required.

The main results of the first part of research allow also to analyse efficiency of the battery and changes in the charge and discharge process. The effects of this part of experiment will be also used to estimate of losses of electrical energy.

This section of measurements pays very important role because BES has been used in a previous research carried out by German co-partners. The main objective of capacity tests was to prepare in the laboratory conditions an actual characteristic of the battery and compare with nominal parameters.

The evaluation of the measuring results from the second part could allow to assess an influence of the BES on the basic parameters of a power distribution system, e.g. energy flows, voltage level, harmonic content. Additionally, some observation of changes of basic technical parameters of battery energy storage in the operation process also will be also made.

According to a research assumption the first stage of research included the capacity test of energy storage device. In order to monitor and meter the key-parameters of BES, a special system with ability of measuring and registration has been installed (Figure 4). The control system consists of measurement modules LEM and LV25-800, LA 100P and LA 55 P. Voltage and current profiles have been registered by oscilloscope TEKTRONIX THS 710 series and special software ANAGRAF v. 5.1 for data processing. Analysis of harmonic distortion was carried out with 0,2% sensitivity. Measurements are carried out by the research team from Faculty of Electrical Engineering of Bialystok Technical University.

Researches was carried out for different states of BES running (charge, discharge, idle running) and for two levels of battery current: 200 A and 400 A. During the tests, a temperature of battery was regularly controlled. The experiment was interrupted when the temperature exceeded 40°C.

According to the recommended practice for testing lead-acid batteries, a capacity test started from discharging battery and then a charge process was examined. All parameters have been registered in 30 minutes intervals. In order to audit the battery voltage in a stable state, that parameter has been additionally measured after 5 minutes after the first stage.

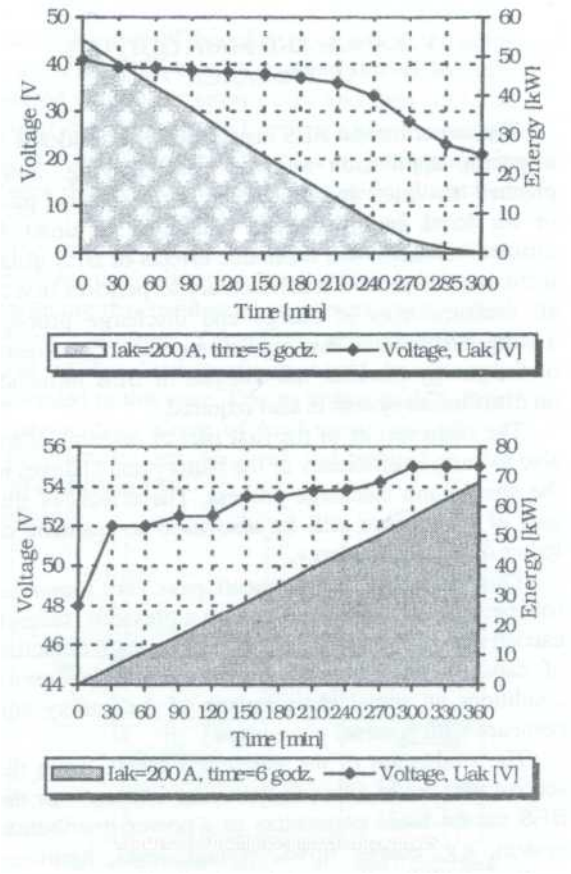

Figure 3. Discharge and charge curves

In the paper the results of capacity tests with direct current 200 A are only submitted. In discharging process it was observed that in the first period of the operation voltage slightly declines and when the batteries achieved practically a discharging level, the voltage immediately decreases. When the battery is switched off the voltage achieves its nominal value. The battery was discharged during five hours. Energy output in that process equalled 45,1 kW. Whereas during the next stage, e.g. battery charging, energy input amounted about 68 kW (Figure 3). Charging curve has a relatively linear character. The energy efficiency of full cycle (discharge and charge) is less than 70%. Achieved results indicate that potential benefits could be smaller that it was expected.

Harmonic analysis of the off-load voltage shows an evident distortion caused by the 3^{rd} (1,1 %), 5^{th} (3,1%) and the 7^{th} harmonic (1,0 %). A high level of the voltage distortion has a significant influence on the quality of a distribution system. In the examined case coefficient of total harmonic distortion in the off-load state equalled 4 %. But the achieved results of distortion do not exceed Polish standards of energy quality for power distribution network operating at the voltage lower than 1 kV.

Within the scope of the presented project an active filter was designed and constructed. In the figure 4 the module scheme of BES installation with the active filter is presented. The main purpose of that filter is to minimise disadvantageous influences of BES on distribution feeder. The idea of that system is based on such a bridge control, which allows to introduce an additional current required for achieving sinusoidal curve of voltage and current into the system.

From economic point of view usage of that kind of filter could reduce costs coming from energy tariff regulations (charges for reactive power, voltage distortion).

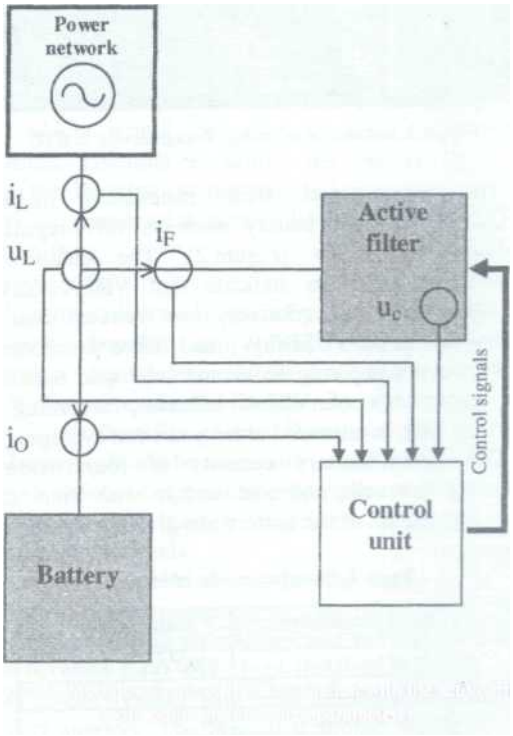

Figure 4. Module scheme of BES installation with the active filter (with point and measured parameters)

On the present stage of the project only simulation work on BES installation with active filter has been completed. The researches in this problem are in progress, so it is difficult to present any detailed date from that part of the experiment. But the initial results of simulations show positive and significant influence of that element on the quality of the output energy. Total harmonic distortion coefficient in a current, for instance, thanks to active filter was reduced from 0,26 % to 0,14 %. Achieved figures from simulations will be verified and compared with the results of measurement tests.

VI. DIRECTIONS OF FUTURE RESEARCH

The results of the experiment achieved so far have been used in evaluation of charge and discharge process and BES influence on power system quality.

In order to install energy storage devices in the power network it is necessary to continue research in the following fields:

- long-term capacity tests,
- quality research,
- load measurements in separated part of local energy markets.

It is planned that BES application in power distribution network would be possible after additional modelling and simulation of load levelling effect.

The obtained results of laboratory tests would allow verifying potential benefits or losses that could be consequences of the implementation of the battery energy storage in the distribution network.

Taking into account ecological regulations of Polish energy law and peculiarity of the north-eastern part of Poland it could be purposeful to consider a non-traditional BES application. Conditions and existing infrastructure, e.g. small wind power plants could be a good base for a new approach to the BES usage. It seems that a combined system consisting of renewable source and energy storage devices could be, in specific conditions, an effective option from technical and economic perspective.

VII. CONCLUSIONS

This paper includes only initial outputs of the experiment. On that stage of the project it is impossible to draw final conclusions about usefulness of battery energy storage in the power distribution network. The recommendation of BES usage by the power utilities could be made on the base of final results of the project. But in authors opinion even initial results could confirm potential effectiveness of energy storage devices in the existing conditions of Polish energy market [3],

It is planned that the achieved results could be also a good point of reference to prepare an international proposal of Joint European Project within the confines of 6th Frame Programme granted by EU. Presentation of the key-aspects of the project could be treated as an invitation for the future co-operation in the range of the energy markets and integrated resource planing. More detailed information about researches are available by personal or e-mail contact with the supervisor of the research team.

VII. ACKNOWLEDGEMENT

The paper includes overview of the project sponsored by State Committee for Scientific Research (KBN) under contract G/WZ/1/01.

VIII. REFERENCES

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PROFILE OF THE RESEARCH TEAM

Scientific researches of the team centre on technical and economical aspects of energy markets. The key-subjects of the studies are focused on load management (forecasting, estimation), supply restoration, energy loss evaluation, voltage quality. The research interests are also connected with modelling and analysis of distribution systems in uncertain conditions, application of expert systems, a fuzzy theory to power distribution system calculations. Team co-operates with both national and foreign academic centres and industrial partners.