QUASI-AUTONOMOUS PHOTOVOLTAIC APPLICATION IN NORTH REGIONS

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Abstract. Quasi-autonomous photovoltaic (PV) technology is a PV based solar energy use system for electricity production with electricity accumulators and connection to the grid. This type of PV technology has a wider application range due to benefits of combination from autonomous and grid connected systems. Part of PV generated electricity is accumulated till it is the consumption demand. The peak demand and demand in non-sunny seasons are covered from the grid. Reduced electricity re-load from the grid has economical advantages, as well as it is beneficial to energetics in overall. Surplus it secures from the grid electrical interruption effects. Electrical accumulator use significantly increases the costs of the PV based system. As well not all of accumulators are suitable for lot of full charge/discharge times. Moreover, they are limited lifelong. In most of cases, accumulator often replacement is inexpedient from ecological and maintenance points of view Therefore, calculation of appropriate electricity accumulators for long time use is very necessary. This paper provides review of the most widespread quasi-autonomous technologies, analysis of electricity accumulator long-life in solar energy applications. As well, the paper describes appropriate use of quasi-autonomous PV application in agriculture field.

Keywords: solar energy, photovoltaic, PV, electricity accumulation.

Introduction

It is hard to reduce the importance of solar energy in agriculture field. Direct solar energy and humidity play the main role of agriculture yield. Hence, cultivation, harvesting and handling processes ask for additional energy. Solar energy equipment could produce auxiliary energy. Photovoltaic elements are used for electricity production, and solar collectors – for thermal energy production.

Ever-decreasing costs of the system components combined with energy-efficient concepts in the area of solar energy technologies open new opportunities for application of photovoltaic and solar thermal systems in different agriculture sectors. The dynamics of PV installation is inversely proportional to initial investments in terms of Euro/kWp. The price reduction for PV products in the last decade is in proximity to 10 % [1] a year, and every year the lowest cost records per installed PV nominal power are set for systems of all scales.

Wide photovoltaic applications are detected in counties with high-developed agriculture and manufactory, see Fig. 1.

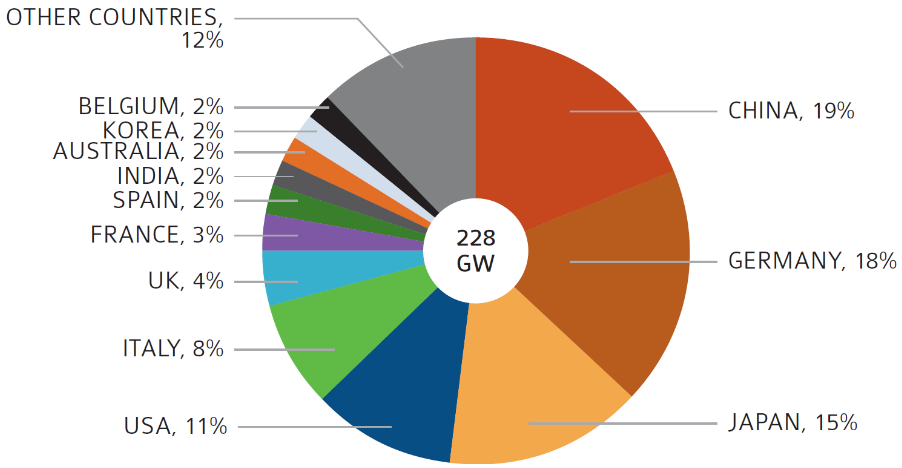

Fig. 1. **Cumulative photovoltaic capacity (end of 2015) [2]**

The main barrier of solar energy equipment applications is the gap between solar energy production and energy consumption. Energy accumulation reduces or even solves this problem. Electricity accumulation technologies are divided into: small-scale – less than 100 kWh, middle-scale – from 100 kWh till 1 MWh, and big-scale more than 1 MWh. Big- and middle-scale electricity accumulation technologies almost do not combine with photovoltaics. Small-scale electricity accumulation technology should meet the following requirements: easy energy charge and discharge;

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small energy losses; compact; transportable; easy installation and connection to the overall energy system. The accumulation technologies that do not meet these requirements or are very uncommon are not included in this paper.

Materials and methods

The paper is based on experimental study, field research, and system monitoring on side. Most of the experiments were done at the "Solar energy testing polygon" that is located in the Institute of Physical Energetics in Latvia. Investigation includes many studies of separate PV and electricity accumulators and some combined systems. The combined system scale is small – till 8 kWp of PV power and till 14 kWh of electrical accumulators. Additionally, lot of monitoring data and practical reviews are received from our colleagues from all over the world.

Result and discussion

If the accumulator is connected in the photovoltaic system, the number of accumulator cycles per year depend on the proportion of the accumulator capacity per PV system daily maximum overproduction and from solar radiation fluctuation during the year. PV system daily overproduction consists of total electricity generation by photovoltaic array minus the energy consumption during the PV generation time. As well, it should be less than the energy that must be saved until the next PV system generation cycle. The number of full accumulator cycles in operation with the PV system is from 330 till 350 times per year in sunny regions with a low number of rainy days. In sunny regions, higher electricity consumption is during the warm season because of high cooling demands. However, installations more to the Poles have exponential reducing of accumulator cycles. Moreover, the difference of solar radiation in different seasons is more than 10 times in colder regions. Surplus, the electricity consumption increases in colder seasons. For example, the number of full accumulator cycles in operation with the PV system is close to 150 times per year in the Baltic Sea states region. Fluctuations between the seasons are shown in Fig. 2.

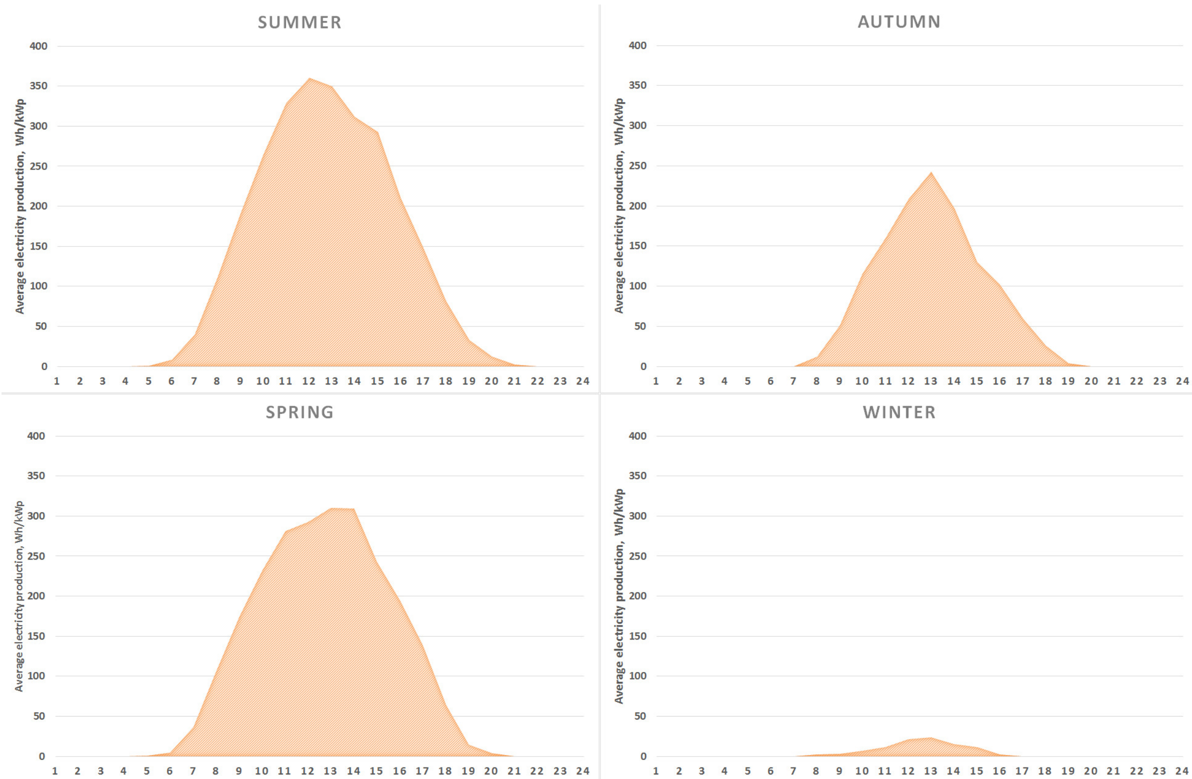

Fig. 2. **Seasonal average PV electricity production per hour in Latvia**

Analysis of energy consumption in agriculture shows that the PV system with accumulation is most suitable for milk production, drying, electric fences for cattle, autonomy drinking bowls, and cooling.

The most widespread electricity accumulator type is lead-acid accumulators. This type of electricity accumulators is used in 60 % cases of the off-grid photovoltaic system. The main reason is very low initial costs. The Absorbent Glass Mat (AGM) is also popular in solar applications. In the last decade, Lithium-ion based accumulators got wide applications in the solar energy usage field. Lithium-ion based accumulators (Li-ion) have increased the charge/discharge cycle, but their initial costs are several times higher than for lead-acid accumulators. Saltwater-based accumulator types are the most nature friendly and safe.

The actual, or in other words – usable, capacity differs from the total accumulator capacity. Most of accumulator types become unusable after discharge under critical level. Often discharge below 50 % of lead-acid accumulator leads to degradation. [3] Discharge below 40 % is enough for irrecoverable capacity decreasing. The deeper discharge – the higher capacity lose. [4] Discharge below 30 % could be only once, because after that lead-acid accumulator charging becomes very inefficient. Even more, active boiling occurs in long time charge after deep discharging in lead-acid accumulators, and could lead to explode. Summarizing, the usable capacity of lead-acid accumulators is 30 – 40 % from the total capacity.

Lead-acid accumulator charging is accompanied with gas bubble appearance near the metal plates. High current charging leads to high pressure in the accumulator. Moreover, this leads to explosion danger. In solar energy use applications, current limitation at constant voltage conditions means solar energy use loses. Thence, it needs to increase the overall capacity of batteries that leads to increasing of the investment costs. Li-ion based batteries have higher charge and discharge current.

Accumulators connected in a row increase the maintenance costs. Each accumulator charging level should be checked approximately once in a week, if the lead-acid accumulator is connected in a row. Charging imbalance between the batteries connected in a row is increasing during the time. Thence, some low-charged batteries should charge up until the overall level. Without this maintenance, accumulator control will overcharge the accumulator in the middle of the row, and the electricity accumulation system will break. Accumulator smart control units exist on the market. Accumulator smart control systems have battery inter balancing. However, in most cases the lead-acid accumulator is chosen in cases with maximal cost reduction, thence, any system improvements are not included in this set.

Lithium-ion based batteries have lower critical discharge level. The recommended discharge level is about 10 %.[4] It is because of discharge under 4 % could lead to pole switch in some cells of Li-ion accumulators. This charging of accumulators most probably will explode. High discharge and over charge are very dangerous for Li-ion batteries; therefore, most of them have inter balancing by default from the manufactures. Long-term full charge provides increased degradation of Li-ion batteries. Therefore, these types of batteries should be discharged at least once in a month for increase of their lifetime.

Sulfate appears at the metal plate at partly discharged lead-acid accumulators. Charge until the maximum level is necessary at least once in a week for preventing fast degradation of the lead-acid accumulator. Lithium-ion types of accumulators have a higher charge/discharge cycle if they work in the range of 50-80 % of the total capacity. Solar energy use has daily and seasonable fluctuation. During the low-sun seasons, the batteries are staying at very low charging level without the accumulator smart control system. It leads to reducing of the lifetime of batteries.

The operational temperature of the batteries mostly depends on the thermophysical properties of the accumulator components. Secondary depending is due to active warming in charging with high current. Especially it is feasible in operation with lead-acid and AGM accumulators. AGM and gel type batteries lifetime reduces 4 times if they operate in temperature +40 ºC instead of the recommended +20 ºC. When the internal temperature of the accumulator charger becomes higher than 40 ºC, the output current decreases.

Depth of accumulator discharge depends on temperature in operation with the Li-ion based accumulator type. The recommended operation temperature is from +23 ºC to +28 ºC. [4, 5] The lower temperature – the lower the capacity of the accumulator could be used for most of the accumulator types. For example, the lead-acid accumulator at -20 ºC has 40 % less capacity comparing with the recommended operation temperature.

Saltwater-based batteries have the operation temperature range from -5 ºC to +40 ºC. It has minimal charging losses dependence from temperature changes. They do not have lifelong reducing dependence from the operation temperature.

All types of batteries should be placed indoor or underground under the freezing depth. The place of the ventilation area depends on the warming intensity during the charging cycle. Not all types of batteries produce noise. Nevertheless, noise production could appear from active cooling of batteries at such system installation.

Installation of lead-acid and AGM accumulator types must be only in well-ventilated area. Li-ion based batteries types should operate in a fire safe place. Li-ion batteries burn temperature is 1'800 – 2'200 ºC. They even produce heat without fire for several days after the fire active phase. It means that conventional fire protection is not suitable for Li-ion placement. It should be noted, that mechanical defects lead to overheating, fire appearance and explosive of most types of electricity batteries. The safest from Li-ion based accumulators is $LiFePO_4$.

The saltwater-based type, such as magnesium water, accumulator is the safest accumulator type for application in the photovoltaic system. They have several benefits: non-toxic, non-caustic, non-flammable, non-explosive, total discharge or low overcharge do not lead to any effect. It is possible to place this accumulator type even in the living area, but electrical protection should be increased according to safety reasons. The main disadvantage of the saltwater accumulator is several times increased weight comparing with other most common technologies.

Table 1

Comparison of main parameters for different types of electricity accumulators per 1 kWh

Parameters	Conventional Lead-acid	AGM deep discharge	Li-ion based	Saltwater based
Usable capacity	35 %	40 %	90 %	100 %
Usable depth of discharge	55 %	45-50 %	95 %	100 %
Charge/discharge cycles till 70 % of capacity	200-300	250-300	1000-1500	3000
Charge/discharge losses, %	25 %	25 %	10 %	10 %
Peak/nominal charge/discharge power, C*	2/0.3	1/0.2	0.78/0.23	1/0.2
Operation temperature, ºC	-20 to +50	-20 to +50	-10 to +40	-5 to +40
Weight, kg	21	25	15	53

*Charge/discharge power shown as ratio from total accumulator capacity (C)

The time of peak charge/discharge is limited, approximately it is several minutes. Peak power is necessary to start driving motors. The smaller the current of charge/discharge – the lower the energy losses. It should be underlined that charging with too low current cannot provide full accumulator charging in case of lead-acid, AGM and gel types accumulators. As well, operation with proper current increases the accumulator lifetime for all types of accumulators. Lead acid and AGM technologies have significant reduced usable capacity comparing to the total capacity. Therefore, proportional increase of the total capacity is necessary to reach the demand of the usable capacity.

Recycling is obligatory for all types of batteries, except the saltwater type batteries. Unfortunately, recycling costs usually are hiding costs. The Li-ion type accumulator recycle costs are 4-10 $EUR \cdot kg^{-1}$, lead-acid accumulator – 2-4 $EUR \cdot kg^{-1}$, AGM – 3-7 $EUR \cdot kg^{-1}$. It is possible to get valuable metals during recycling. Therefore, the end costs of recycling could be positive in some cases. If an accumulator type with a small number of cycles is used, then easy accumulator replacement should be obligatory.

The results of the cost efficiency analysis are shown above. It took into account the initial costs, maintenance and replacement costs (at accumulator capacity drop until 70 % of its usable capacity), electricity loses during charge/discharge cycles, recycling costs. Only good quality accumulators were included in the investigation. Ideal conditions are applied to all types of batteries. Improperly operation conditions will increase imbalance.

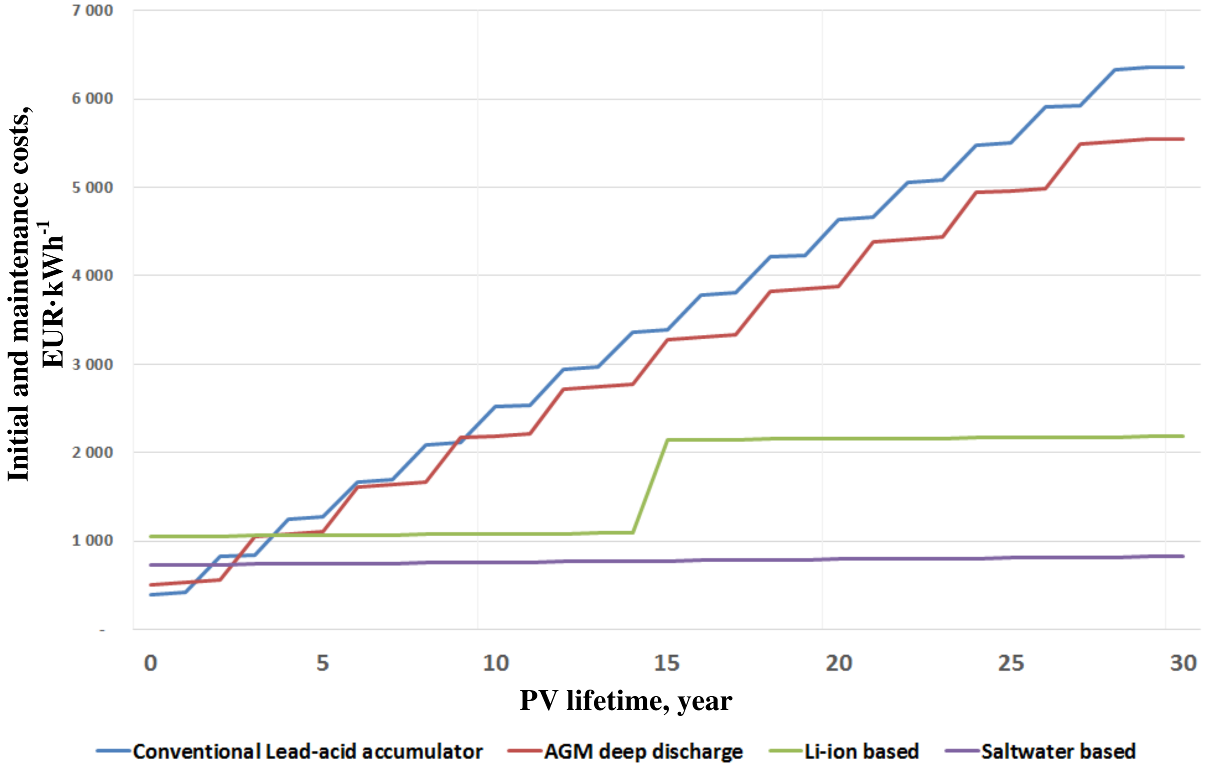

Fig. 3. **Initial and maintenance costs of different electricity accumulators by operation in Northern climatic conditions**

The AGM deep discharge accumulators could operate longer than the conventional lead-acid accumulators. However, the price of AGM deep discharge is also higher than for the lead-acid accumulators. AGM deep discharge could be more reasonably installed in a place with hard replacement conditions. Li-ion batteries have even better cost effective conditions during all PV lifetime. Replacement is needed only once or twice per PV lifetime. The best cost effective technology for PV application is saltwater based. Good quality saltwater accumulators have the operation lifetime close to PV.

Conclusions

Analysis of energy consumption in agriculture shows that the PV system with accumulation is most suitable for milk production, drying, electric fences for cattle, autonomy drinking bowls, and cooling.

The most widespread electricity accumulation technology in combination with photovoltaic systems is lead-acid based and AGM accumulators. It has the lowest initial costs. But it has a very limited number of charge/discharge cycles. Losses of charge/discharge are very high, surplus charging over 80 % of the battery total capacity should be with low current. It leads to solar energy losses.

Lead-acid based accumulator expenses during all photovoltaic system lifetime are 2.9 times higher comparing to Li-ion based accumulators, and 7.7 times – comparing with saltwater-based accumulators.

Li-ion accumulators could operate under high peak power for the longest time. However, operation over nominal power significantly reduces the lifetime of any accumulator type.

Saltwater accumulators are used to operate all photovoltaic systems with the lifetime 25-30 years, without replacement. As well, it is the safest accumulator type.

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