# Large Supercapacitor Sets in Alternative Energy and Power Quality/Energy Distribution Systems.

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## Introduction.

Aspects of developing alternative (renewable) energy are under close attention of highly developed states governments. A few of European countries suppose to reach the alternative energy level of 10% among all the using kinds of energy to 2011 year. In some of USA states, especially in Colorado, wind energy systems are widely used, photovoltaics, biogas etc. are usual among private companies.

Nowadays, power quality systems and energy distribution are becoming more and more important, not just because of full and qualitative energy supporting, but as a factor of country economical security. The damage from long power blackouts proves the necessity to modernize the Main Power Supply Lines substations and systems.

Traditionally, the storage battery is used as an intermediate power source between the primary alternative source and the consumer. The battery provides some autonomy of Main Power Supply Lines substations.

In the present article types of power sources for the application, mentioned above, are analyzed. It is shown that the battery is not an optimal choice and, in some cases, can not satisfy customers' demands. From the other hand, electrochemical capacitors (supercapacitors, ultracapacitors, etc.), possessing a set of unique qualities, can be used more optimal, in some cases excluding battery using.

# 1. Power Sources for Alternative Energy and Power Quality

## 1.1. Primary power sources.

Nowadays, the most typical primary power sources produced by the industry are:

- solar cells( photovoltaics);
- wind generators;
- small hydroturbines.

These systems get energy directly from nature, unlike other multistage sources of energy transformation, for example: biogas, fuel cells. Such proximity to processes of nature determines their strong dependence from their fluctuation. Variability of solar activity, wind intensity, duration etc. cause an unstable power output of the primary power sources mentioned above. Not only during the day but during one hour and even several minutes output characteristic of current and voltage may change in the range of ± 40 %! It is natural that none of consumers can use and work with the energy of any primary source with the direct connection to it. That is why the using of the secondary power source is needed, where this source is a buffer between the primary source and the consumer.

## 1.2. Secondary power sources.

The most technically developed power source, having wide industrial availability is batteries. Rarely, electrolyzer cells with the storage of gases and its following consuming in fuel cells are used. Potential energy is also tried to be stored in a state of pressed air with its using by means of pneumoturbines.

The batteries of traditional electrochemical systems such as lead-acid and nickel-cadmium are used as secondary power sources for alternative energy. The size of the secondary source is varied and, depending on an exact object, can keep energy for using during one or tens of hours.

Batteries are mostly satisfied customers' demands in case of long storage of energy. But they have a list of disadvantages which decrease the efficiency of their application and increases operating costs:

a) at short-time drops of voltage at the input of batteries, it stops charging and can not accumulate energy in a low-voltage range;

b) at short-time surge of voltage at the input of the battery is either overcharged or is switched off from charge by the management system. In this case input energy is dissipated at load resistors if the consumer does not need it;

c) batteries can not accept and store high-power short duration charging pulses (seconds, for example – the wind gust) because of the high inertion of electrochemical reactions inside the batteries .

d) at short-time overload of the output line from batteries the voltage drop of local grid or changing the frequency beyond the output AC generator of grid take place.

e) management system costs a lot as regards the price of batteries and the simplification of automatics leads to some extra-expenses in maintenance of batteries (filling up electrolyte, checking the voltage of each cell etc.)

In the whole, notwithstanding wide application of batteries in alternative energy they are not completely optimal. Deviation of charging current and voltage at the input of batteries, irregular charge-discharge cycles, the probability of the overcharge or overdischarge decrease the effective service life of the secondary power source and do not provide us with normal application during many years.

## 1.3. Electrochemical capacitor is a secondary power source for alternative energy and power quality.

Let's recall the place of electrochemical capacitors (EC) among traditional power sources, according to some main consumer qualities (table 1).

Table 1

| **Parameters** | **Traditional capacitors** | **Electrochemical capacitors** | **Batteries** |
|---|---|---|---|
| 1. Speed of action(RC time constant) | Very high (RC: 0,005-0,3 sec) | **Very high (RC: 0,07-0,5 sec)** | Very low (RC: thousands of seconds) |
| 2. Energy density | Very low (≈0,2 KJ/kg) | **Acceptable, middle (1-30 KJ/kg)** | High (>100 KJ/kg) |
| 3. Specific power | Very high in discharge pulse | **Very high (5-20 KW/kg)** | Very low (<1 KW/kg) |
| 4. Service life | High(millions of charge-discharge cycles) | **High(millions of charge-discharge cycles)** | Low(thousands of charge-discharge cycles) |

It is clear from the table that electrochemical capacitors take an intermediate position between traditional capacitors and batteries, having preferential indexes of both of them.

Let's observe the possibilities of capacitors in reference to alternative energy and power quality in comparison with batteries:

a) equivalent series resistance (ESR) of EC is very low (small value of RC) that makes it possible to absorb and store energy of power pulses of current and voltage with the duration from 100 milliseconds to 100 seconds with the efficiency more than 90%;

b) fast response of EC makes it possible to reach the maximum power (load) during 5-20 microseconds! Thus, there won't be any current or voltage drops in transient processes of the grid overload and also there won't be phase excursions of the output AC generator;

c) electrochemical capacitors are independent on the irregularity of charges and discharges, do not have «memory effect», allows the discharge to the reversing in polarity and short circuit without performance degradation;

d) EC – are sealed devices and also integrators of the accumulated electricity, this fact simplifies the content and the algorithm of management system work. Moreover, EC do not need maintenance during exploitation, that in the whole practically exclude the operating expences;

e) service life of EC is much more higher than one of batteries. There are proving facts for ELIT capacitors – 25.000.000 charge-discharge cycles with the depth of discharge 20%.

Having enumerated all the comparative advantages, we should not forget about disadvantages, the only one here – is low energy density. Capacitor sets may improve and support the grid in periods of higher needs during several minutes is maximum. In the whole, application of batteries for systems, depending on the time of day – photovoltaics, can not be excluded. But in this case the using of EC is economically approved as «mishaps» of transient processes either at the input or at the output of batteries are excluded. Operational conditions of batteries are improving and the service life is increasing. It is also possible to lower the capacity of batteries at the expense of the transmission of «powerful» functions to the capacitor set.

For other systems of alternative energy (wind- and hydrogenerators, fuel cells) it is possible to eliminate batteries as the secondary power source between the primary source and the consumer.

We shall point to some additional advantages of EC:

- the absence of electrochemical reactions at EC electrodes with kinetic dependence, lower temperature influence, which make EC operation in wider temperature range possible while it is impossible for batteries.
- most EC do not contain toxic components in active masses and electrolytes (systems with aqueous electrolytes solutions) and during the operation (and after that) do not give off any substances in the environment.

## 2. The Application of the Electrochemical Capacitors in Alternative Energy.

The simplified scheme of using of EC in systems with the primary *photoelectric* source and secondary *low-voltage* batteries is given at figure 1.

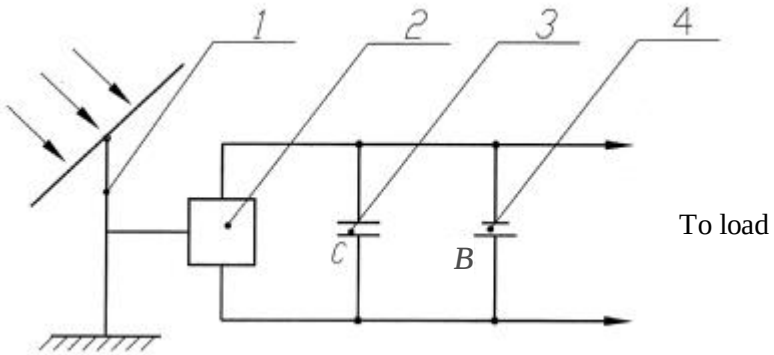


*Fig.1.The principal scheme of connecting of EC for stabilization of the low-voltage grid.*
*1 - photocells (solar panel); 2 – management system; 3 – EC; 4 – battery.*

More complete and more interesting using of EC in large high-voltage grids with AC consumers is given at figure 2.

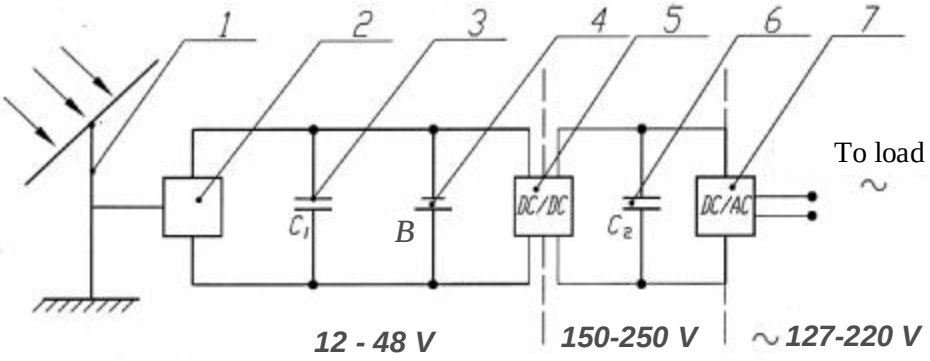


*Fig.2. The principal scheme of connecting of EC for stabilization of the high-voltage grid.*

*1 – photocells (solar panel); 2 – management system; 3 – EC; 4 – battery; 5 – DC/DC converter (direct-current); 6 – EC for stabilization of the high-voltage consumer grid; 7 – DC/AC converter (alternating current).*

In all these cases EC energy store is calculated according to the covering of 75 – 85% of energy, that is required in the high-power discharge. It means that batteries are protected from overloads and are discharged in long and middle modes. Besides, the presence of the high-voltage capacitor before the DC/AC converter improves the power quality in consumer's AC grid.

In wind-power engineering, a capacitor set is placed between the wind generator and the consumer with no using of batteries. Various cases, including windmills with an AC generator, where EC support the grid through AC/DC – DC/AC converters, working in on-line mode are possible. EC energy store is mostly determined by the power of the wind generator and the grid which it powers and is varied from tens of kJ to MJ.

Let's observe a specific example:

*500 kW supercapacitor set for a wind generator.*

Initial data:

| | |
|---|---|
| 1. Maximum power | 500 kW |
| 2. Average power | 200 kW |
| 3. Maximum operational voltage | 800 V |
| 4. Nominal operational voltage | 600 V |
| 5. Minimum operational voltage | 400 V |
| 6. Daily overload numbers | 250 |
| 7. Temperature range | -25°C…+50°C |
| 8. Required time for supporting wind generator | 4…7 sec |

Capacitor set parameters:

| | |
|---|---|
| 1. Electric capacitance | 15,38 F |
| 2. Equivalent series resistance | 0,023 Ohm |
| 3. Energy store | 3, 08 MJ |
| 4. Output energy at 200 kW discharge | 1,75 MJ |
| 5. Discharge duration (200 kW) | 8,7 sec |
| 6. RC time constant | 0,36 sec |
| 7. Efficiency of power conversion | >97% |
| 8. Peak power | 4,2 MW |
| 9. Set weight | 2700 kg |
| 10. Set volume | 1,7 cub.meters |

The simplified scheme of connecting the set is given at fig.3

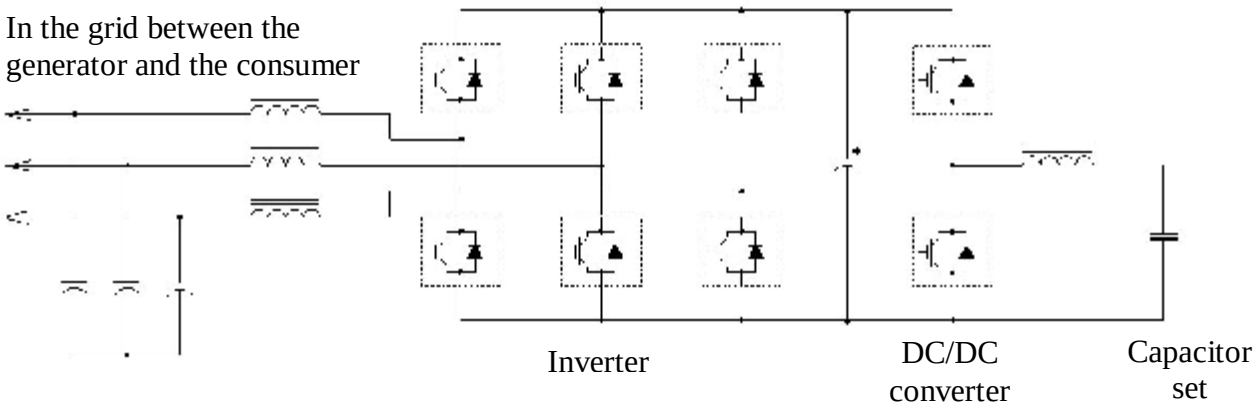


*Fig.3*

In this case, the capacitor set is used in the normal undercharged condition. At small energy consumption in the grid and short-time overdose of input energy from the wind generator, the set is charging to maximum state of charge (SOC) and keeps this excess till it is needed. In the case of the overload of the consumer's grid, the capacitor set covers transient processes and discharge from the medium or maximum SOC.

From the analysis of the initial data and capacitor set parameters, it's clear that no one battery can work effectively in such a wide voltage range and with such a high voltage. Besides, none of existing high-voltage batteries can be of a size of 1,7 cub. meters and can provide peak power of 2,5 kW/l.

## 3. Electrochemical Capacitors in Power Quality Systems and Energy Distribution.

3.1. On-line systems of an uninterruptable supply in large industrial grids.

In such systems EC sets work as short duration UPS (to 1 min.), solving transient processes problems in case of lines overloads, short-time fluctuation of current, input and output voltage and frequency.

The scheme of typical connecting for on-line short duration UPS is given at fig.4.

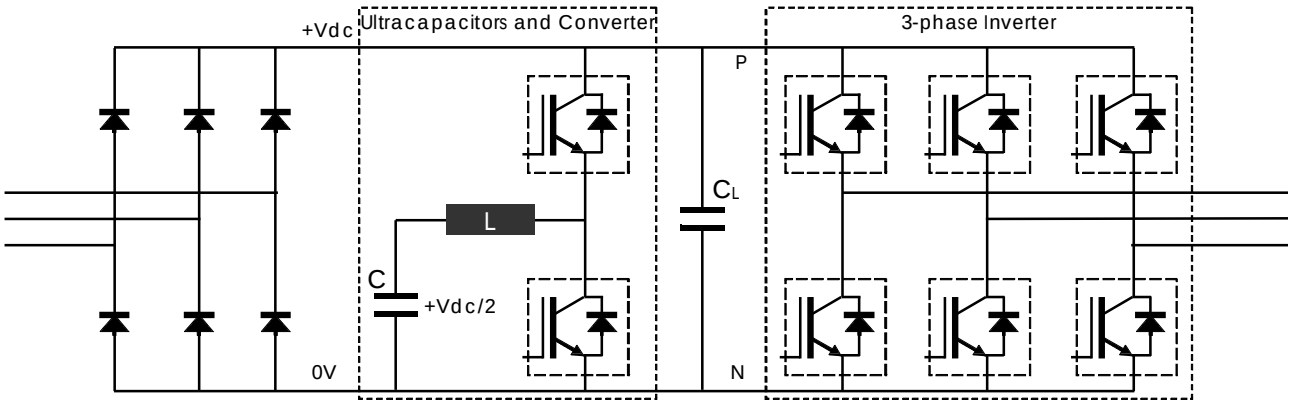


*Fig. 4.*

A specific example of realization of short duration UPS – 10 kW, 30 sec.:

EC set characteristics:

| | |
|---|---|
| 1. Nominal operational voltage | 200 V |
| 2. Capacitance | 22 F |
| 3. Equivalent series resistance | 0,016 Ohm |
| 4. Energy store | 457 kJ |
| 5. Discharge duration 200 V → 100 V, 10 kW | 33 sec |
| 6. Set weight | 180 kg |
| 7. Set volume | 170 lit |

For comparison, to realize this process with the help of lead-acid batteries, 50 cells with the capacitance of 150 Ah must be installed. With the energy density of stationary batteries – 30 Wh/kg, system weight will be 500 kg, instead of 180 kg of EC. Besides, it's impossible to solve transient processes problems.

3.2. The modernization of static compensators at high-voltage Main Power Supply Lines substations.

Frequent cases of energy supply blackouts in large regions (New York – 2003, Moscow – 2005) make utility companies improve their substations. Their main goal is to avoid «avalanche-like» disconnection of substation because of short-time Main Power Supply Lines overloads.

Traditionally, static compensators just regulated reactive power, achieving the minimization of phase angle shift. In this case, usual capacitors, working at the industrial frequency (50, 60 Hz) are used.

However, STATCOM can not support Main Power Supply Lines in case of voltage failure in the grid (≈100 milliseconds) or somehow balance transient processes of this effect.

Nowadays, there exists a tendency of providing substations with one's own power source for a short-time supporting the grid. The type of the power source is high-capacious capacitors. Energy store for compensation is 1…3 MJ, time of supporting ≈2 sec.

Two main types of compensation are developing:

a) Sinusoid of AC cycle is forming by the short-time switching of DC capacitors in the discharge with the changing quantity of connecting cells.

The main ideology and technical realization are given at fig.5.

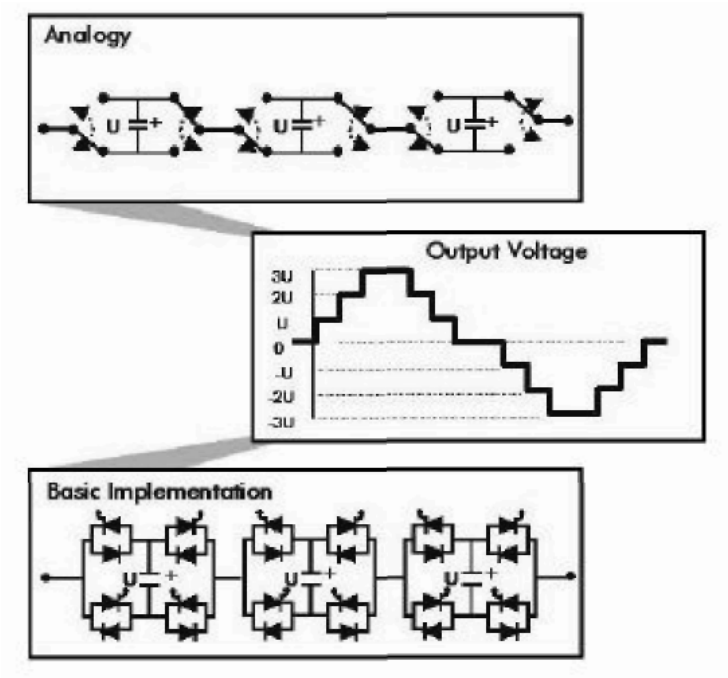


Fig. 5

For realization of this scheme EC with RC time constant < 10 milliseconds are needed. It is possible for EC systems with aqueous solution of electrolyte.

b) The parallel connection of the capacitor set through the voltage up DC/DC converter and then through DC/AC inverter.

It is practically the scheme of short duration UPS, described in section 3.1 of the present article. The only exception is that the connection does not go in the on-line mode through the grid but there is a connection, parallel to the grid. A specific example of realization is like the description in section 3.1. Necessary energy store

and operational voltage of the substational power source are taken by the series-parallel connection of EC sets or EC modules, which they consist of.

## Conclusions.

1. Electrochemical capacitors can be effectively used in alternative energy, replacing storage batteries in systems, independent on time of the day (wind- and hydroenergy, fuel cells…). Besides, problems of qualitative energy supply are solving thanks to the exclusion of transient processes in case of grids overloads.
2. Electrochemical capacitors can be effectively used in power quality systems and energy distribution. Besides, problems of the stability of Main Power Supply Lines substations to short-time overloads are solving and the probability of «avalanche-like» disconnection of Main Power Supply Lines is considerably decreased.

Thus, in every place, where there are unstable energy flows, EC can solve these problems. Large supercapacitors sets provide stable power from 30 microseconds to tens and hundreds of seconds in periods of instability or interruption in the grid.

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ALEXEY I. BELYAKOV

## Brief Biography

### Title: General Director of ELIT JSC.

Alexey Belyakov has more than 25 years of Experience in research, development and manufacturing of Electrochemical Power Sources. In 1988 he was titled "the Best Technologist of the Year" by the Power Sources Department of the USSR Ministry of Electrotechnic.

In 1991 - 1995 he was a leader of some State scientific-technical programs in the Ministry of Science of Russia, Expert in Electrochemical Power Sources of Department of Science.

From the year of 1996 he became one of the leaders of the Florida Seminars (FESI, Deerfield Beach, FL) on "Double Electric Layer Capacitors and Similar Energy Storage Devices", presenting yearly talks on diverse problematic aspects of development and application of Electrochemical Capacitors.

In the 1990s Alexey Beliakov with a team of co-authors discovered and patented a new electrochemical system for capacitors: "Carbon/MeOx".

Alexey Beliakov has published 30 articles, on electrochemical capacitors mainly, and have obtained 21 patents on Electrochemical Power Sources.

Since 2001 he is an active international member of the Electrochemical Society (ECS), Pennington, New Jersey, USA.

“Who’s who” Historical Society (USA) recognized A.Belyakov having demonstrated exemplary achievement and distinguished contribution to the business community (2004-2005 edition of International “Who’s Who of Professionals”).