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ENERGY ANALYSIS OF LOAD VARIATION INFLUENCE OVER DC BUS WITH ULTRACAPACITOR

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Abstract: *In the paper mathematical relations between main energy parameters of DC bus with ultracapacitor and dc load variations are presented. Analysis is based on MATLAB and graphical results and expressions are shown. DC bus voltage level, voltage instability, capacitance of ultracapacitor, level of load power changing and time-reaction abilities of converters connected to the DC power bus are investigated.*

Key Words: ***Electronics/ DC/DC Bus/ Ultracapacitor***

1. INTRODUCTION

DC voltage is produced to supply constant or variable dc loads, to supply dc-to-ac converters, which could be autonomous or depending of the utility grid. In many cases dc power is delivered from different sources. A lot of DC consumers require uninterruptible supply system for their reliable operation. Those facts impose the need of parallel connection of different dc sources through dc converters to common DC supply bus. Some of DC loads have own dynamic behavior, so the power consumption could be changed very rapidly from one level to another. So the fast reaction of dc converters supplying DC bus must be achieved. Sometimes is difficult to fulfill such hard requirements. The control features of system with parallel connected dc-to-dc or ac-to-dc converters are already described [1,4]. System using energy from fuel cells and operating in parallel with ultracapacitor also is analyzed together with control problems [3, 5].

The same approach to the problem could be applied and deeply investigated with a system of parallel connected dc converters.

In the present paper system of parallel connected dc converters to common DC bus is investigated (fig.1). An ultracapacitor is included in parallel to DC bus to achieve better dynamic performance.

The features of energy processes during transient conditions are analyzed in connection with the level of dc voltage, the capacitance of ultracapacitor, variation of dc power consumption.

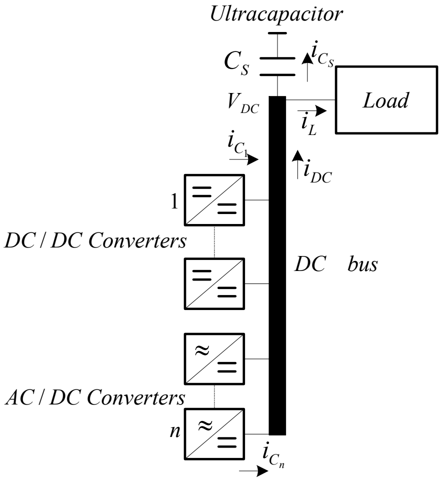


Fig.1. System block diagram

2. MATHEMATICAL DESCRIPTION

The DC bus current i_{DC} derives from several DC/DC or AC/DC converters as shown in fig.1. On the other hand this current divides to load current i_L and ultracapacitor charge current i_{Cs}. According to Kirchoff's low

$$i_{DC} = \sum_{k=1}^{n} i_{C_K} = i_{C_S} + i_L \qquad (1)$$

Main variables which are used in the analysis describes as follows:

C_S – capacitance of ultracapacitor, F ;

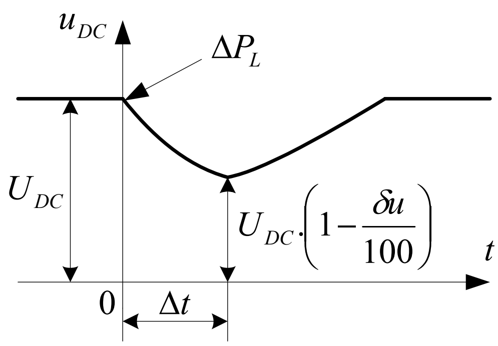
ΔP_L – the step change of load power, W ;

S_{DC} – speed of converter reaction, W/s ;

δu – DC bus voltage variation, $\%$;

U_{DC} – dc bus supply voltage, V.

When a sharp shange of load consumption occurs the DC bus voltage is changed, such as shown in fig.2. It is considered that at instant t=0 power consumtion of dc load increases with ΔP_L. So, during time interval Δt, the DC bus voltage falls and then begins to recover the initial value. Output power of the input converters is settled to the new higher value after a certain delay. Recovery time of DC bus voltage depends on the value of dc voltage and converter's abilities – type of control and time reaction.



Фиг.2. DC bus voltage as a function of the load power step change

After the DC bus voltage instability the converters increase their output power. This higher power level will be established in time Δt, which describes as

$$\Delta t = \frac{\Delta P_L}{S_{DC}} \qquad (2)$$

A linear variation of converters otput power is assumed.

Because of delayed converter's reaction initially the ultracapacitor supplies increased load consumption. The power transmitted from capacitor to the load is given by

$$P_{C_S}(t) = \Delta P_L - S_{DC}.t \quad \text{за} \quad 0 \le t \le \Delta t \qquad (3)$$

Therefore the energy transmitted is

$$\Delta W_{C_S} = \int_0^{\Delta t} P_{C_S}(t).dt = \frac{\Delta P_L^2}{2.S_{DC}} \qquad (4)$$

On the other hand energy ΔWc could be expressed using voltage U_{DC}. If the initial value of DC bus voltage is changed by δu percent of the nominal rating due to the increased load current then the new value of dc voltage is $U_{DC}(1-\frac{\delta u}{100})$. Consequently an energy change of ultracapacitor is:

$$\Delta W_{C_S} = \frac{1}{2}.C_S.U_{DC}^2 - \frac{1}{2}.C_S.U_{DC}^2\left(1-\frac{\delta u}{100}\right)^2 = \frac{1}{2}.C_S.U_{DC}^2\left[1-\left(1-\frac{\delta u}{100}\right)^2\right] \qquad (5)$$

According to equations (4) and (5) the value of ultracapacitor could be calculated using expression:

$$C_S = \frac{1}{S_{DC}}.\left(\frac{\Delta P_L}{U_{DC}}\right)^2.\frac{1}{1-\left(1-\frac{\delta u}{100}\right)^2} \qquad (6)$$

As expected the capacitance of ultracapacitor depends on change of load power, speed of converter reaction, DC bus voltage variation, dc bus supply voltage. The obtained equation is useful for easy calculation of ultracapcitor capacitance if values of main variables are known.

A MATLAB based analysis is implemented in order to research the particular influence of variables mentioned above.

The capacitance dependence of a load power change is shown in fig.3. Results are obtained at $S_{DC} = 200\,W/s$ and $\delta u = 5\%$.

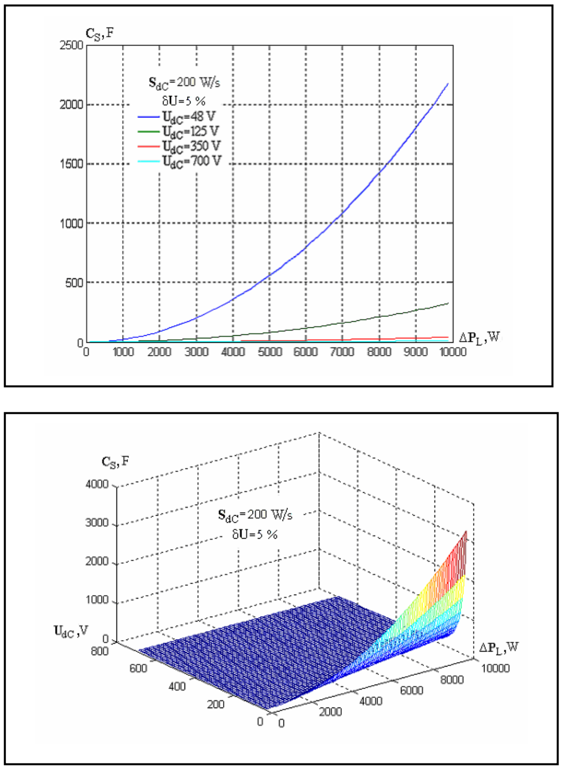


Fig.3. Relationship between the capacitance of ultracapacitor and the load power variation at different DC bus voltages

It could be seen from shown results that larger power change and smaller value of dc voltage require larger capacitance of ultracapacitor.

Next analysis is concerning influence of a load power change and dc voltage variation. Variables assumed are $S_{DC} = 200\,W/s$ and $U_{DC} = 48V$. Results are shown in fig.4.

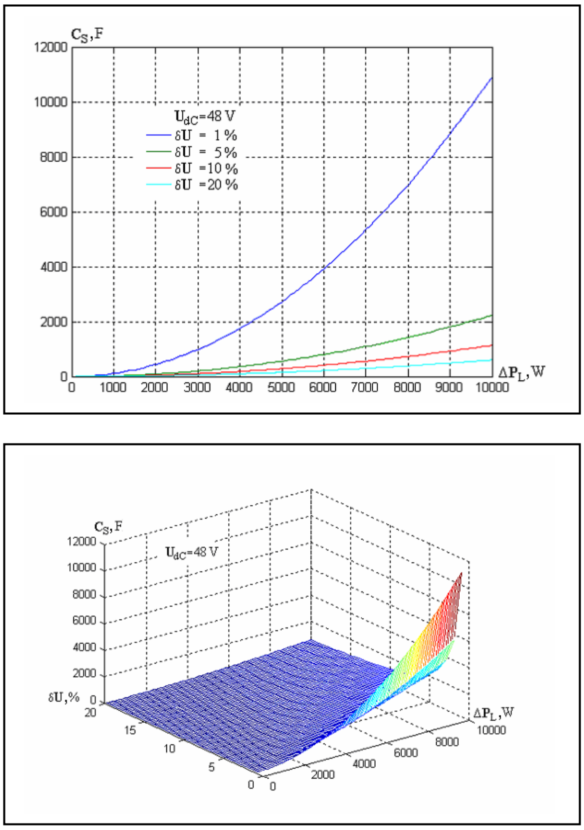


Fig4. Ultracapacitor capacitance as a function of the load power and dc voltage variation

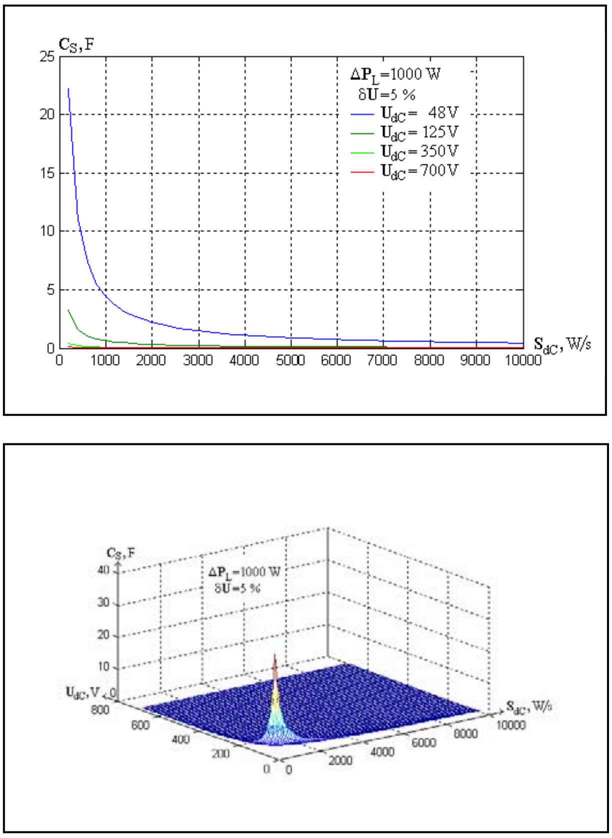


Fig5. Ultracapacitor capacitance as a function of the speed of converter reaction at different dc voltage

It could be seen from shown results that larger power change with smaller voltage variations require larger capacitance of ultracapacitor as it is expected.

Results concernenig converter's abilities – power level and speed of reaction, are shown in fig.5. The ultracapacitance dependancy of converter reaction S_{DC} at different DC bus voltages is investigated. It is assumed constant change of load power and constant dc voltage variation – the choice is $\Delta P_L = 1000W$ and $\delta u = 5\%$.

As faster as converter's reaction the lower is ultracapacitor capacitance. It could be seen that when reaction S_{DC} is faster than a certain level the influence of dc voltage value is reduced.

It is very important to estimate possible internal ultracapacitor power losses. They are determined by capacitor current and internal serial resistance R_{Cs}. Serial resistance couldn't be changed but the current depends on proper design of input converters. Power losses are produced mainly in the interval Δt when ultracapacitor supplies load – the current level is very high. During recovery interval an ultracapacitor charging current could be relatively small and usually power losses could be neglected.

Normally voltage variation δu is relatively very small acording to DC bus voltage U_{DC}. Then the current through the ultracapacitor varies according to the equation:

$$i_{C_S}(t) \approx \frac{\Delta P_L - S_{DC}.t}{U_{DC}} \qquad (7)$$

Hence the energy transferred to the serial resistance of ultracapacitor, cousing it's heating, is:

$$W_{R_{C_S}} = \int_0^{\Delta t} i_{C_S}^2(t).R_{C_S}.dt \qquad (8),$$

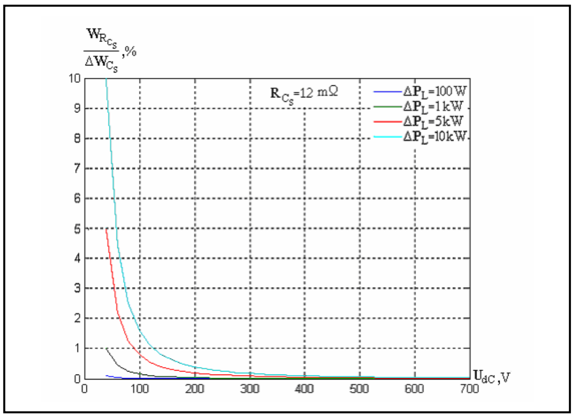
Replacing $i_C(t)$ from (7) and solving the equation is obtained:

$$W_{R_{C_S}} \approx \frac{2}{3}.\frac{R_{C_S}}{S_{DC}}.\frac{\Delta P_L^3}{U_{DC}^2} \qquad (9)$$

The energy losses in reference to transmitted energy from capacitor to load determines by (9) and (5):

$$\frac{W_{R_{Cs}}}{\Delta W_{Cs}} \approx \frac{4}{3}.\frac{\Delta P_L}{U_{DC}^2}.R_{Cs} \qquad (10)$$

The dependance of ratio (10) from DC bus voltage at different load power changes is shown in fig.6. The chosen value of internal resistance is $R_{C_S} = 12m\Omega$. It correspondes to the range of resistance variation for ultracapacitors type BMOD oferred from Maxwell Technology [2].



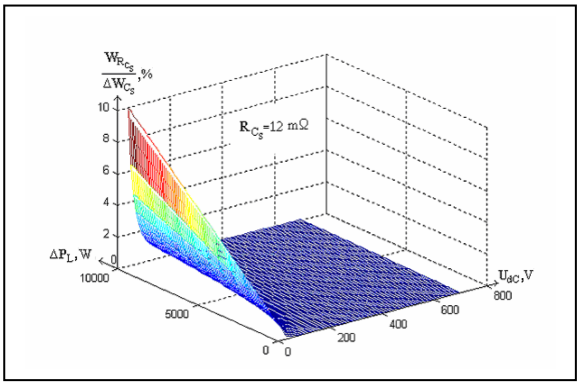


Fig6. The dependance of ratio (10) from DC bus voltage at different load power changes

The plotted grafics shows that energy dissipated in the internal serial resistance in reference to delivered load energy from ultracapacitor corresponds to the changes of load power consumption and decreases with increasing DC bus voltage.

3. CONCLUSION

A system of parallel connected converters supplying a common dc load is analysed. A capacitor named ultracapacitor is connected to common dc bus in order to improve system reaction in a case of sharp load change. An equation (6) is obtained for calculating the capacitance of ultracapacitor. A lot of grafical results based on MATLAB are shown at different DC bus voltages, different levels of load power variation. According to obtained equation (10) is possible to estimate dissipated internal power in ultracapacitor for certain application and to make a proper choice of dc converter control. The obtained expressions and grafical results provide a possibility for optimal choice of ultracapacitor capacitance for definite application and to complete the requirements towards the system of paralel connected converters supplying common dc load.

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