Capacitance Size of Active Power Filter: Buck-Type vs. Split DC Link

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Capacitance Size of Active Power Filter: Buck-Type vs. Split DC Link

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***Abstract*—In this working paper the size of the required capacitance of an active power decoupling / active power filter for a single phase rectifier is evaluated based on power flow considerations.**

***Index Terms*—Active Power Filter, Single Phase PFC Rectifier Ripple Energy Storage.**

I. Introduction

In the literature various circuits have been proposed for filtering/buffering the fluctuating power ripple p_r (see figure 1), which is inherently given in single phase rectifier systems.

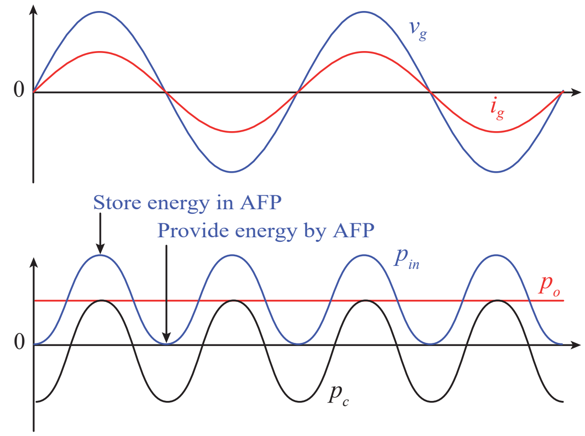

Fig. 1. At the top the waveforms of the grid voltage v_g and current i_g of a single phase grid and at the bottom the idealised waveforms for the power flow from the grid are given. There, p_{in} is the input power of the rectifier, P_o the average output power (average value of p_{in}, and p_r is the power ripple / fluctuating power.

For example, in [1] a bidirectional buck–boost converter is investigated as the ripple energy storage circuit for single phase rectifiers. The basic circuit is shown in figure 2, which is called buck-boost type active power filter (BBT-APF) in the following. The minimum required capacitance value is derived in [1] to be equal to

$$C_{BBT,min} = \frac{2P_{APF}}{\omega V_{DC}^2} \tag{1}$$

There, it is assumed for simplicity that the voltage V_{BBT} across the buffer capacitor varies from 0 V to the DC link voltage V_{DC}. In this equation P_{APF} is the fluctuating power / power ripple, which should be buffered in the ripple energy storage circuit. In a real system, the technically usable capacitor voltage range is often chosen to be smaller due to operational/controller constraints.

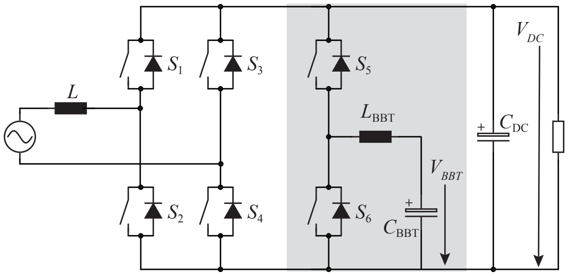

Fig. 2. Circuit diagram of buck-boost type active power filter (BBT-APF).

As an alternative, in [2], [3] a buck-boost converter is presented, which is connected to the midpoint of the split DC-link capacitor as shown in figure 3. This circuit is called sDC-APF in the following and it has the potential advantage, that the capacitors $C_{sDC,l}$ and $C_{sDC,u}$ for buffering the power fluctuations can also be used as DC link capacitor.

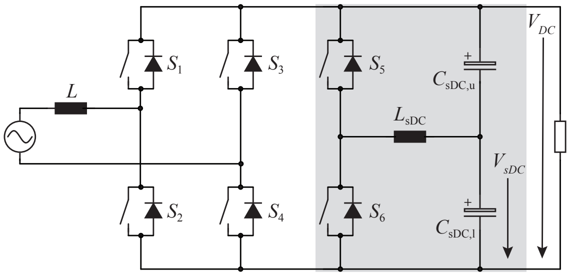

Fig. 3. Circuit diagram of split DC link capacitor active power filter (sDC-APF).

If the midpoint voltage V_{sDC} of the DC link is fully varied again for simplicity between 0 V to and V_{DC} for buffering the energy, each of the two capacitors $C_{sDC,l}$ and $C_{sDC,u}$ in the AFP must have at least the following capacitance value as derived in [2].

$$C_{sDC,min} = \frac{4P_{APF}}{\omega V_{DC}^2} \tag{2}$$

Consequently, the total capacitance for the split DC link capacitor APF is 4 times as large as the total capacitance for the buck-boost type APF. However, in case of the sDC-APF the two series connected capacitors $C_{sDC,l}$ and $C_{sDC,u}$ can be also used as DC link capacitor. In the following, the question is discussed, why the required capacitance for the sDC-AFP is four times the capacitance value of the BBT-AFP.

1) Power Flow: Considering the power flow in the active power filters, which are shown in figure 5 for the sDC-APF and in figure 4 for the BBT-APF, the reason for the higher

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Thanks to Min Jeong for drawing the figures.

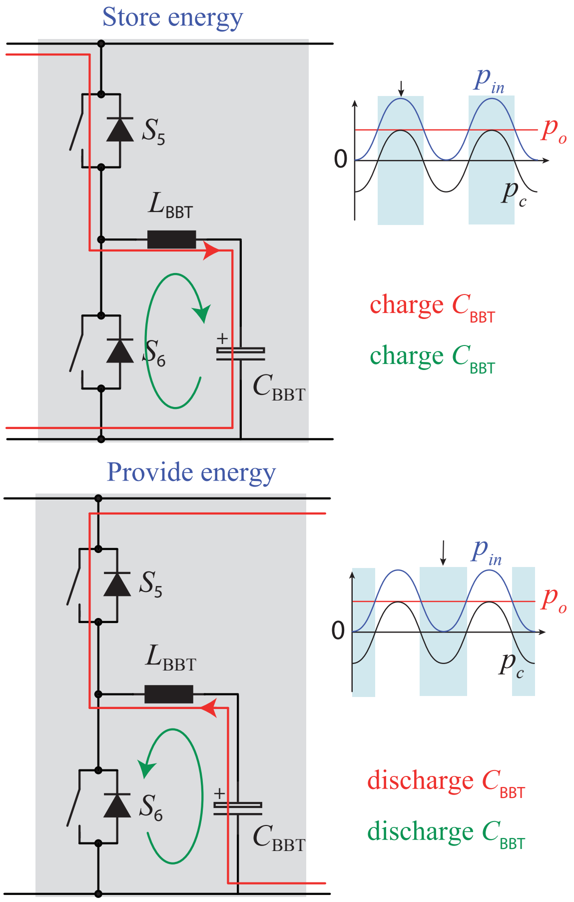

Fig. 4. Power flow in the BBT-APF. Top figure for storing excess energy from the grid and bottom figure for releasing excess energy to the load. The green arrows show the "current"/"power" flow for switch S_6 being closed and the red arrows for switch S_5 being closed.

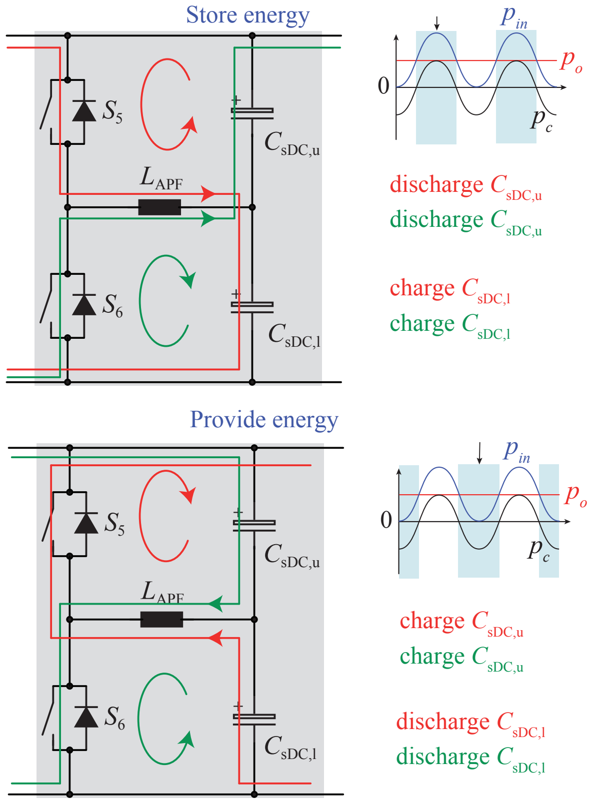

Fig. 5. Power flow in the sDC-APF. Top figure for storing excess energy from the grid and bottom figure for releasing excess energy to the load. The green arrows show the "current"/"power" flow for switch S_6 being closed and the red arrows for switch S_5 being closed.

required capacitance values in case of an sDC-APF becomes clear. In the respective top figures the power flow for storing excess/surplus energy from the grid in the capacitors and in the bottom figure the power flow for releasing excess energy to the load are shown. There it could be seen, that in case of the BBT-APF the capacitor C_{BBT} is used for storing/buffering the energy. However, in case of the sDC-APF, only the lower capacitor $C_{sDC,l}$ is used for storing the energy. The upper capacitor $C_{sDC,u}$ is releasing energy to the DC link / load in case excess energy should be stored in the APF and it is storing energy from the grid in case excess energy should be released to the DC link / load. Therefore, the upper capacitance is not only not supporting the energy storage of the APF, but in contrast even opposing the storage task, so that in $C_{sDC,l}$ also the energy must be buffered, which is released / buffered by $C_{sDC,u}$. Thus, the total required storage capacitance is twice the value of the one for the BBT-APF and due to the series connection of $C_{sDC,l}$ and $C_{sDC,u}$ the total capacitance is even 4 times as large as $C_{BBT,min}$.

2) Stored Energy: Instead of the power flow also the stored energy in the capacitors of the sDC-APF could be considered in order to derive the required capacitance values. Starting at the "idle" point $V_{sDC} = \frac{V_{DC}}{2}$ the amount of stored energy in $C_{sDC,l} = C_{sDC,u} = C_{sDC}$ is equal to

$$\begin{aligned} E_{sDC,total,V_{DC}/2} &= 2 \times \frac{1}{2} C_{sDC} \left(\frac{V_{DC}}{2}\right)^2 \\ &= C_{sDC} \frac{V_{DC}^2}{4} \end{aligned} \tag{3}$$

If the voltage V_{sDC} is increased to V_{DC} or decreased to 0 V, always one of the two capacitors is completely discharged and the other one is charged up to V_{DC}. Therefore, the maximal amount of stored energy in the APF is

$$E_{sDC,total,V_{DC}} = \frac{1}{2} C_{sDC} V_{DC}^2 \tag{4}$$

The energy variation between $E_{sDC,total,V_{DC}}$ and $E_{sDC,total,V_{DC}/2}$, which could be used for buffering the energy fluctuations from the grid, is equal to $C_{sDC}\frac{V_{DC}^2}{4}$ in case of the sDC-APF. In contrast the usable energy variation for the BBT-APF is between 0 J for $V_{BBT} = 0$ V and $\frac{1}{2} C_{sDC} V_{DC}^2$ for $V_{BBT} = V_{DC}$. This shows again, that the total required storage capacitance is four times as big for the sDC-APF compared to the BBT-APF.

3) DC Link Capacitance: The effective DC link capacitance for the sDC-APF is equal to $C_{sDC,min}/2$ due to the series connection, what is equal to $C_{BBT,min}$. If in case of a rectifier system with a BBT-APF the difference between the required amount of capacitance $C_{BBT,min}$ for the BBT and

4x$C_{BBT,min}$ for the SDC-APF is installed as DC link capacitor, the effective DC link capacitance would be 3x$C_{BBT,min}$.

II. CONCLUSION

Considering the above derivations regarding the power flow and energy storage, it becomes clear from a physical/circuit point of view, that the BBT-APF is utilising the given capacitors much more ”efficiently” compared to the sDC-APF.

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