ENHANCE THE STEADY STATE PERFAMANCE OF THE SINGLE PHASE RECTIFIER WITH ACTIVE POWER DECOUPLING TECHNIQUE

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Abstract- **New regulations impose more stringent limits to current harmonics injected by power converters, what is achieved with Pulse Width Modulated (PWM) rectifiers. In addition several applications demand the capability of power regeneration to the power supply. As we know conventionally we can filter ripple power with the help of bulky capacitors and LC filter which yields poor power density, so another way is to employ active power decoupling that uses an active kind of circuitry for directing pulsating power to another type of energy storage element which further reduces dc-link capacitor. In our proposed circuit employs a third leg, smoothing inductor and energy storage capacitor, all these topology provides high storage efficiency and low control bandwidth. When deriving power decoupling scheme pulsating power from ac source and reactive power of smoothing inductors are taken into account. Also here capacitor voltage reference is changed drastically in a closed loop to achieve steady-state perfrormance. We also simulated results with Matlab Simulink and studied power decoupling performance.**

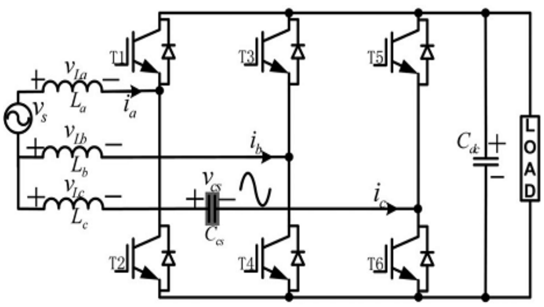
Index Terms—**Power electronics, ripple power, high-power factor, Active power decoupling**

I. INTRODUCTION

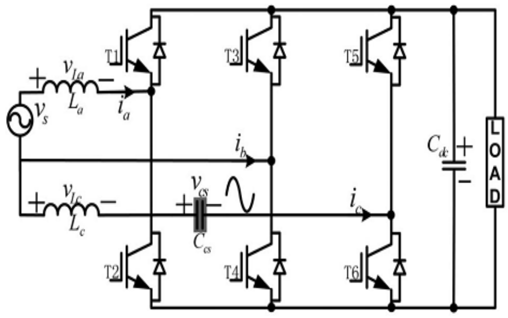
The AC-DC conversion is used increasingly in a wide diversity of applications: power supply for microelectronics, household-electric appliances, electronic ballast, battery charging, DC-motor drives, power conversion, etc... [1].As shown in Fig. 1 AC-DC converters can be classified between topologies working with low switching frequency (line commutated) and other circuits which operate with high switching frequency. The simplest line-commutated converters use diodes to transform the electrical energy from AC to DC. The use of thyristors allows for the control of energy flow. The main disadvantage of these naturally commutated converters is the generation of harmonics and reactive power [1], [2]. Harmonics have a negative effect in the operation of the electrical system and therefore, an increasing attention is paid to their generation and control [3], [4]. In particular, several standards have introduced important and stringent limits to harmonics that can be injected to the power supply [5], [6], [7].A good estimate of the active and reactive powers. However, there are several applications where energy flow can be reversed during the operation. Examples are: locomotives, downhill conveyors, cranes, etc... In all these applications, the line side converter must be able to deliver energy back to the power supply. Various active power filters (APF) [2], [8]–[14] are then proposed to overcome the shortcomings of passive power decoupling. The basic idea is using an active circuit to divert the ripple power from the dc link to another energy-storage component, which permits much larger fluctuation of the voltage or current, therefore both this component and the dc-link capacitor can be small in size and weight. If a capacitor is selected as the energy storage component, film type capacitors can be used, which have a much longer lifetime than electrolytic ones.

II. POWERFLOWANALYSIS

The circuit in Fig. 1 can be considered as a three-phase unbalanced system.



(a)



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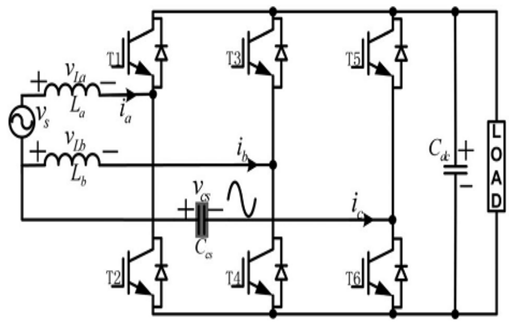


(c)

Fig. 1. Proposed APF topology. (a) Basic form. (b) With $\boldsymbol{L_b}$=0. (c) With $\boldsymbol{L_c}$ =0.

Taking the three output voltages of the three phase legs as controlled voltage sources v_a,v_b,v_c, the equivalent circuit for Fig. 2(a) is shown in Fig. 2.The circuit has higher efficiency than those using inductors as their energy-storage components. All of these features are very important for high-power applications of single-phase PWM rectifiers.

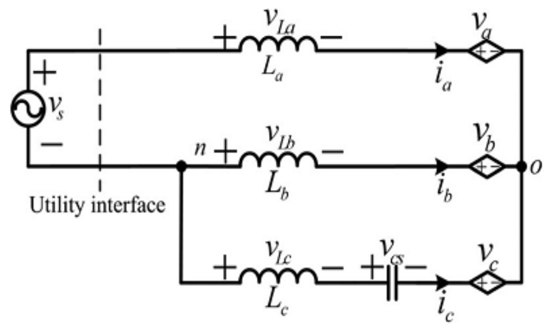


Fig. 2. Equivalent circuit of the single-phase PWM rectifier with the proposed APF.

A. Reference Voltage for Cs

Suppose the ac source voltage and current to be

$$\boldsymbol{v_s = V_s sin(\omega t)} \ldots\ldots..\mathbf{1}$$

$$\boldsymbol{i_a = I_a sin(\omega t)} \ldots\ldots..\mathbf{2}$$

and the voltage and current of the storage capacitor to be

$$\boldsymbol{v_{cs} = V_{cs} sin(\omega t + \theta)} \ldots\ldots..\mathbf{3}$$

$$\boldsymbol{i_c = I_c cos(\omega t + \theta)}$$

$$\boldsymbol{= \omega C_s V_{cs} cos(\omega t + \theta)} \ldots.\mathbf{4}$$

Since it is a three-phase three-line system, we have

$$\boldsymbol{i_a + i_b + i_c = 0} \ldots\ldots\ldots.\mathbf{5}$$

B. Discussion on Current Stress

The compensating current $\boldsymbol{Ic}$ from the third leg will inevitably change the phase-B current$\boldsymbol{I_b}$. It is important that current stress of this phase does not see an excessive increase.

The amplitude of compensating current Ic is related to Cs.According to the proposed design principles Ic will be on the same order ofI_b. Taking these into consideration, the phasor diagram of the three-phase current can be drawn as Fig. 3. The diagram shows that amplitude of phase-B current$I_b$can actually become smaller with the proposed APF.

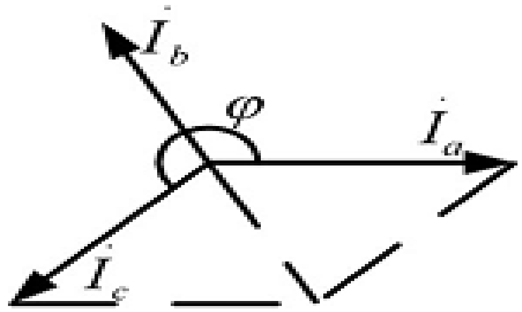


Fig. 3. Phasor diagram of the three-phase currents.

C. Relationship between Power Mismatch and Ripple Voltage

Considering parameter deviation in practical applications and steady-state error in the capacitor voltage control, it is difficult to achieve perfect power decoupling (i.e., no residual ripple power in the dc link). Relationship between power mismatch and dc-link ripple voltage needs to be further investigated in order to design the control parameters of the closed-loop modification properly.

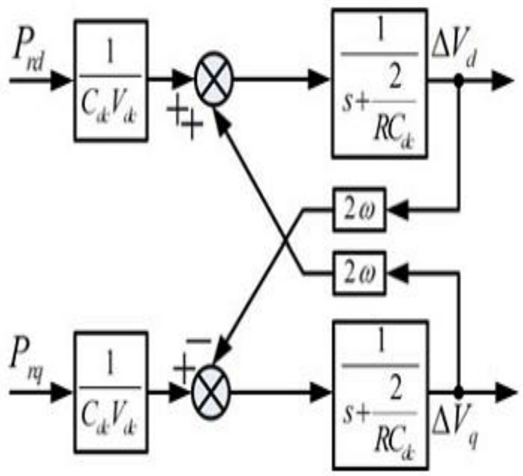


Fig. 4. Relationships between power mismatch and ripple voltage.

III. CONTROLSTRATEGY

In our proposed paper, voltage control is selected for the purpose of easier implementation. Now the transfer function from APF output voltage$\boldsymbol{V_{bc}}$c to capacitor voltage$\boldsymbol{V_{cs}}$is

$$G_v(s) = \frac{1}{L_c C_s S^2 + r C_s S + 1}$$

A. Closed-Loop Modification of Voltage Reference

To minimize the power mismatch (i.e., the residual ripple power in the dc link) due to parameter deviation and limitations of the voltage control system, a closed-loop modification of the voltage reference according to ripple voltage components $\Delta\boldsymbol{V_d}$and $\Delta\boldsymbol{V_q}$ is employed, as shown in Fig. 5.

The modification process is basically a closed-loop regulation of the ripple components, which are good indicators of power mismatch (P_{rd}andP_{rq}). Fig. 6 depicts the control system overview for the APF and the rectifier as a whole. It includes the control system of the rectifier, the subsequently including a utility current inner loop and a dc-link voltage outer loop.

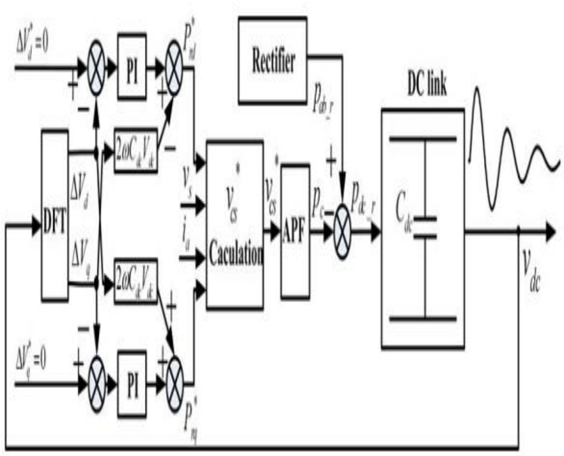


Fig. 5. Closed-loop modification of the voltage reference according to ripple voltage components.$\Delta\boldsymbol{V_d}$and $\Delta\boldsymbol{V_q}$

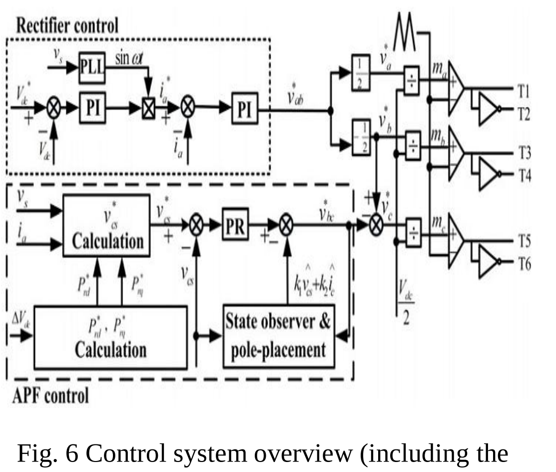


Fig. 6 Control system overview (including the rectifier and the APF).

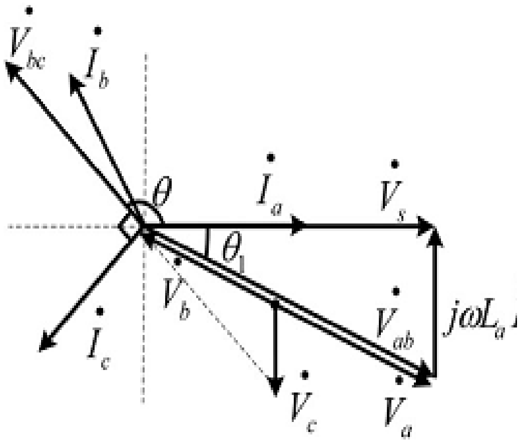


Fig 7 Phasor diagram of the system.

Fig. 7 shows the phasor diagram of the system depicting the power decoupling relationship.

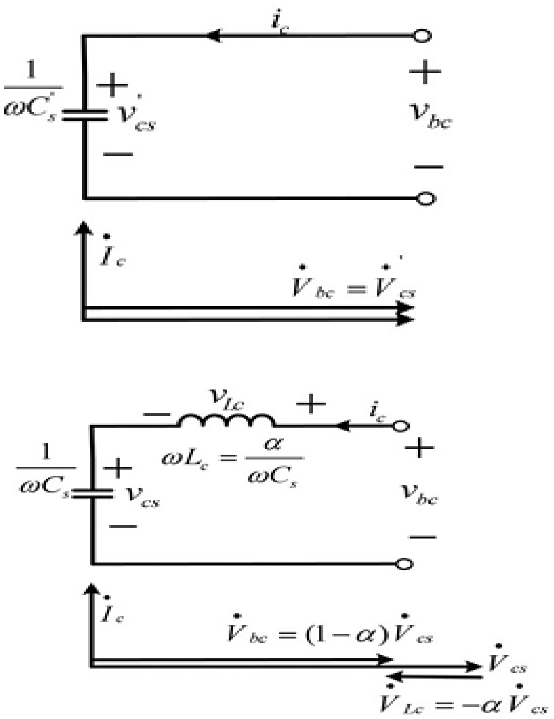


Fig. 8. APF branch with (a)$\boldsymbol{L_c}$=0and(b) $\boldsymbol{L_c}$ ≠0

In CCM operation, the smoothing inductor L_c will consume some reactive power that is in opposite direction to that of the capacitor.In Fig. 8(a)$\boldsymbol{L_c}$ =0 is assumed; whileFig. 8(b) reflects the real case $\boldsymbol{L_c}$ ≠0If we require that theoutput voltage and current of the APF (i.e.,$\boldsymbol{V_{bc}}$and$\boldsymbol{I_c}$) bothremain the same, then the capacitance in Fig. 8(b) has to be smaller than in Fig. 8(a).

A decrease in capacitance seems not bad; however, it should be noted that the capacitor now has to withstand a higher voltage and therefore higher reactive power. The increased part of the reactive power is consumed by the smoothing inductor.

IV. EXPERIMENTAL RESULTS

To study the operation of the DPC/PWM rectifier, it is implemented in MATLAB/SIMULINK environment. It can be seen that both phase-B and phase-C currents are on the same order of phase-A current, indicating no excessively high-current stress on these phases. Therefore, identical power devices can be used for all three phases.

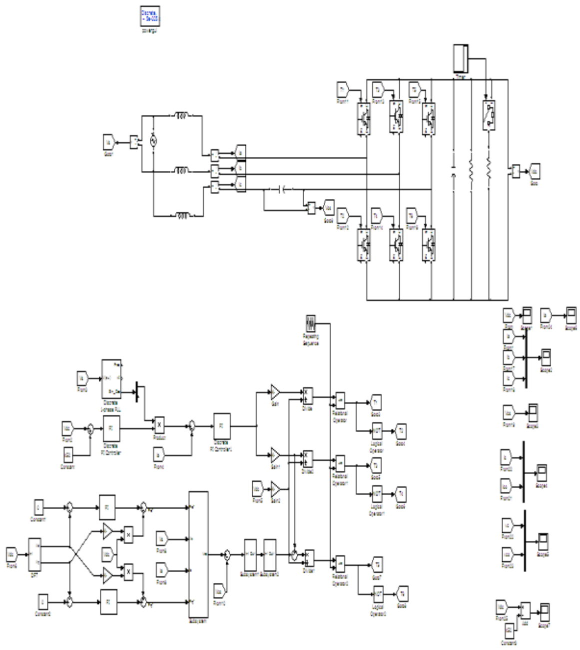
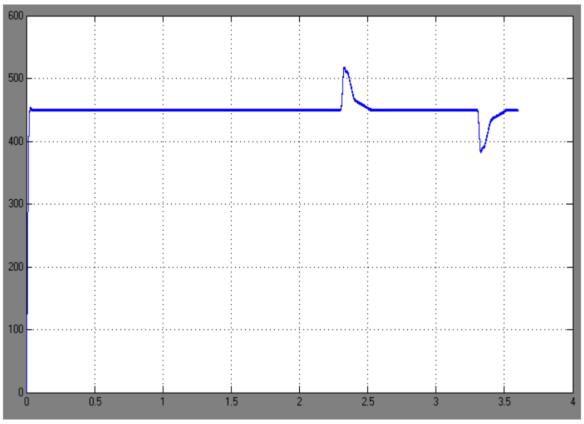
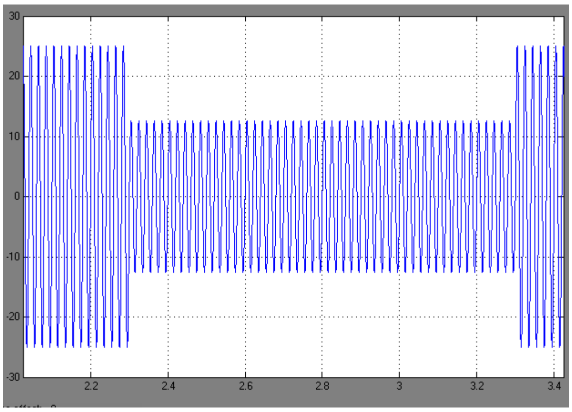


Fig. 9. Model diagram of single phase rectifier for active decoupling





Simulation results.Fig. 10(a) shows the transient response of the systemwhile the load changes abruptly.

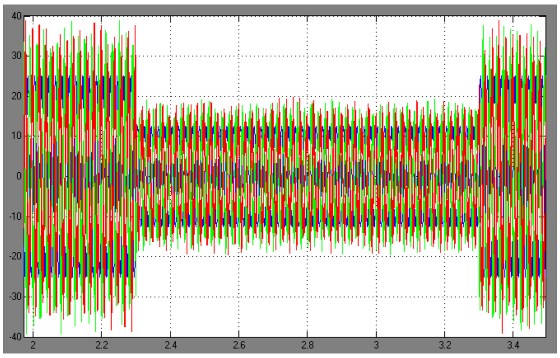


Fig. 10. Experimental results. (b) Transient response to sudden load changes

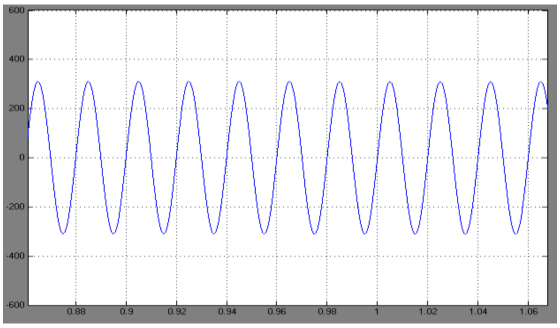


Fig. 10. (c) Observation result of capacitor

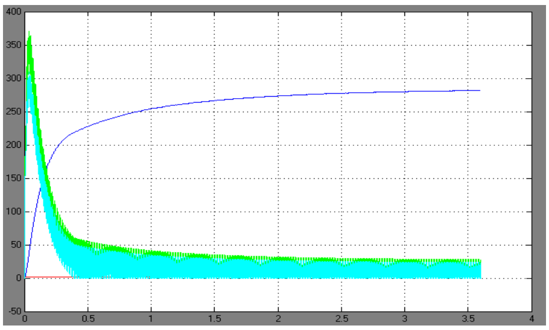


Fig. 10. (d) DC motor performance.

V. CONCLUSION

The main advantages are 1) high efficiency due to capacitive energy storage (as compared with inductance energy storage); 2) low requirement for switching frequency/control bandwidth; 3) full utilization of the capacitor's energy-storage capability; and 4) no excessive current stresses of the power devices. When deriving power decoupling scheme pulsating power from ac source and reactive power of smoothing inductors are taken into account. Also here capacitor voltage reference is changed drastically in a closed loop to achieve steady-state performance. Especially relevant is to mention that single-phase PWM regenerative rectifiers are today the standard solution in modern AC locomotives.

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