단위 역률을 갖는 직렬공진형 단상 정류기의 모드 변환 제어기법

정영석°, 문건우, 윤명중
한국과학기술원 전기및 전자공학과

Switched Mode Control Tcchnique for the Series Resonant Sigle-Phase Rectifier with Unity Power Factor

Young Seok Jung°, Gun Woo Moon, and Myung Joong Youn
Department of Electrical Engeering
Korea Advanced Institute of Science & Technology

Abstract: A buck-boost zero current switched(ZCS) series resonant AC to DC converter for the DC output voltage regulation together with high power factor is proposed. A dynamic model for this AC to DC converter is developed and an analysis for the internal operational characteristics is explored. With the proposed control technique, the unity power factor and the DC output voltage regulation without a current overshoot can be obtained.

1 Introduction

In order to obtain the high quality AC power lines and EMI requirements, it is necessary for many power electronic equipments to improve the waveform quality of the AC to DC conversion. Recently, there has been a great deal of researches on the wave shaping of the active line current in manner of the hard switching. This type of approach for the line condition, however, has many problems such as the high switching losses and high EMI level due to the hard switching [1-3]. To minimize these problems, the resonant converter concepts are promising as they eliminate the switching losses to a great extent such that the switching frequency can be increased and the level of EMI is reduced [3-5].

The boost converter has an advantage which a continuous inductor current in AC line can be controlled to get a unity power factor. However, there exist an inherent disadvantage such that the uncontrolled range exist during the output voltage less than the source voltage. So, it results in the large current overshoot in the start-up transients and much higher ratings of the switching device are required for the safe operation. To overcome above disadvantage, the buck operation should be employed for the improved control performance and system design optimization in the start-up transient periods. The buck converter has the characteristics which deteriorates the input power factor because the input current is discontinuous. Although, the buck converter has an disadvantage, it never shows the current overshoot in the start-up transient periods. Thus, the buck operation is very useful to reduced magnitude of the current overshoot. In this paper, it is basically considered that the fast transient response without a

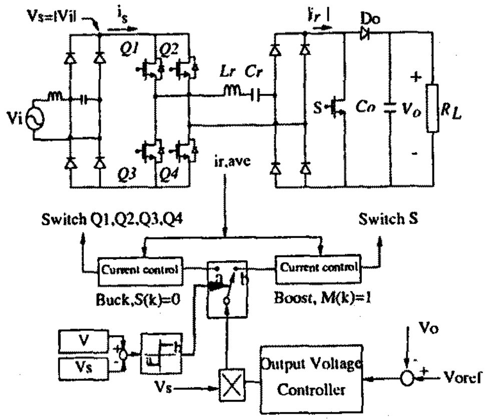
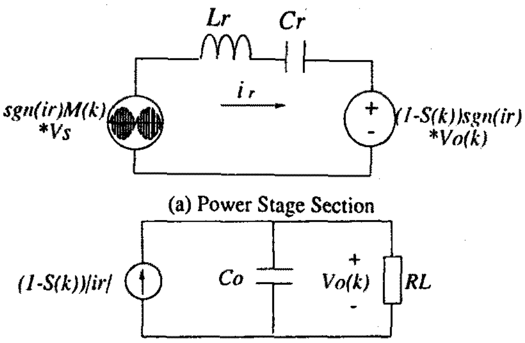


Fig. 1. Circuit Diagram of switched buck-boost ZCS Series Resonant AC to DC Converter.



(a) Power Stage Section

(b) Output Side Section

Fig. 2. Equivalent Circuits of the Series Resonant Rectifier

large current overshoot can be available by fully utilizing both the possible operational modes.

2 Basic Operation and Problem Statement

2. 1 Principles of Basic operation

2. 1. 1 Buck Operation

If a chopper switch S is open, the proposed converter can be classified into the buck converter. In this case, the output voltage is less than the input voltage. The resonant current is increased by using the powering mode and is equal to the input current as shown in Fig 3(a). On the other hands, Fig. 3(b) shows a detailed operational principles and an equivalent circuit for the free-wheeling mode. As can be seen in this figure, the zero voltage is applied to the resonant thank circuit. Thus, the amplitude of the resonant current is decreased and the input current is zero.

2. 1. 2 Boost Operation

The operation of the ZCS series resonant AC to DC converter with the boost characteristics can be easily obtained using the chopper switch S. The switch pairs Q1, Q4 and Q2, Q3 are always turn on and off alternatively in zero crossing points of the resonant current. It is noted that the rectified line voltage to the resonant thank circuit is always in phase with the resonant current. Thus, the resonant power stage is continuously energized by the rectified line voltage and the input current is equal to the resonant current.
Using the powering mode, the amplitude of the current can be rapidly increased with a maximum slop when a switch S is closed as shown in Fig. 4(a). If S is open, as can be seen in Fig. 4(b), the output stage is connected in series with the resonant thank circuit and hence the stored energy in the resonant power stage is transferred to the output stage. In steady state, the value of the output voltage is generally much larger than that of the source voltage in the boost operation. Thus, the amplitude of the resonant current is decreased when the chopper switch S is open.

2. 2 Problem Statement

The boost type ZCS series resonant AC to DC converter has many advantages over the conventional boost type PWM converters such as the zero switching loss, smaller filter, and lower EMI level etc. Furthermore, it shows a much smaller steady state peak current level than a buck type ZCS series resonant AC to DC converter. However, the constraint on the use of the operational mode causes the uncontrollable range in the transient period. Much higher ratings of the switching devices are, thus, required for the safe operation. In this paper, it is basically considered that the fast transient response without a large current overshoot can be available by fully utilizing both the possible operational modes and the switching signal for S.

3 Dynamic Modeling

The dynamic equations for the kth time event which covers the all types of the quantum SRC can be obtained from Fig. 1 and Fig. 2 as follows:

$$sgn(i_r(t))M(k)v_s(t) = L_r\frac{i_r(t)}{dt} + v_c(t) + (1-S(k))sgn(i_r(t))v_o(t) \quad (1)$$

$$C_r\frac{dv_c(t)}{dt} = i_r(t) \quad (2)$$

$$(1-S(k))|i_r(t)| = C_o\frac{dv_o(t)}{dt} + \frac{v_o(t)}{R_L} \quad (3)$$

where M(k) has the values of 1, 0, and -1 denoting the powering, free-resonance, and regenerating mode, respectively, and S(k) has the values of 0 and 1 expressing the on and off state of switch S, respectively. The absolute resonant current can be derived from (1) and (2) by using assumption in [6-7] as follows:

$$|i_r(t)| = \frac{v_c^*(t) + M(k)v_s(t) - (1-S(k))v_o(k)}{Z}\times \sin\{\omega_r(t-kT/2)\},\quad for\, kT/2 \le t \le (k+1)T/2 \quad (4)$$

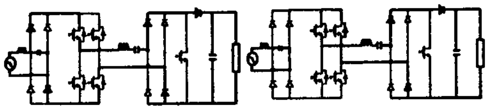
where $Z=\sqrt{L_r/C_r}, T=2\pi\sqrt{L_r/C_r}, \omega_r = 1/\sqrt{L_r/C_r}$, and $v_c^*(k)$ is defined as the absolute value of $v_c(k)$. If the average value of the absolute resonant currnt, $i_{r,ave}^*(k)$, and the output voltage, $v_o(k)$ are defined as state variables, then the state equation is

$$\begin{bmatrix} i_{s,ave}(k+1) \\ v_o(k+1) \end{bmatrix} = \begin{bmatrix} 1 & -\frac{4}{\pi Z}(1-S^*(k+1)) \\ \frac{\pi Z\gamma}{2}(1-S(k)) & 1-\gamma^* \end{bmatrix} \begin{bmatrix} i_{s,ave}(k) \\ v_o(k) \end{bmatrix} + \begin{bmatrix} 4v_s(k) \\ 0 \end{bmatrix} M^*(k+1) \quad (5)$$

where,

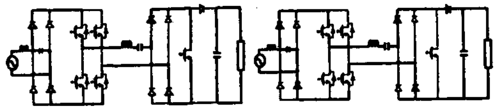
$$S^*(k+1) = \frac{S(k)+S(k+1)}{2},\quad M^*(k+1) = \frac{M(k)+M(k+1)}{2}$$

The equation (5) can be reduced to a dynamic model for a quantum buck SRC if S(k) is set to zero, and this becomes a dynamic model for a quantum boost SRC if M(k) is set to unity.



(a) equivalent circuit for the powering mode case of ir > 0 (b) equivalent circuit for the free-wheeling mode case of ir > 0

Fig. 3. Buck operation of ZCS series resonant converter



(a) The switch S is closed, case of ir > 0 (b) The switch S is open, case of ir > 0

Fig. 4. Boost operation of ZCS series resonant converter

4 Simulation

The advantage of the proposed control technique are comparatively illustrated with the other types of the typical control techniques. Fig. 6 shows the waveforms of the line voltage, line current, and output voltage of the switched buck-boost type control. It can be said that the line current show the sinusoidal waveforms keeping in phase with the line voltage. Thus, the unity power factor can be obtained for both control techniques. For the purpose of comparision, the rectified line voltage, line current, and output voltage of a boost type ZCS series resonant AC to DC converter using a bang bang type current control technique are simulated as shown in Fig. 5. It shows, however, large current overshoot and undesirable output voltage response. As expected, these problems are effectively overcome using the proposed switched buck-boost control as shown in Fig. 6. Since the reduced current overshoot can be obtained, system design optimization with respect to the ratings of the switching device can be possible. Furthermore, it shows a better output voltage transient response and the buck-boost operation can also be availabe.

5 Conclusions

A buck-boost zero current switched(ZCS) series resonant AC to DC converter for the DC output voltage regulation together with high power factor is proposed. The proposed single phase AC to DC converter enables a zero current switching operation of all the power devices allowing the circuit to operate at high switching frequencies and high power levels. A dynamic model for this AC to DC converter is developed and an analysis for the internal operational characteristics is explored. Based on this analysis, a switched buck-boost current control technique is investigated and its advantages over the other types of current control techniques are discussed. With the proposed control technique, the unity power factor and the DC output voltage regulation without a current overshoot can be obtained.

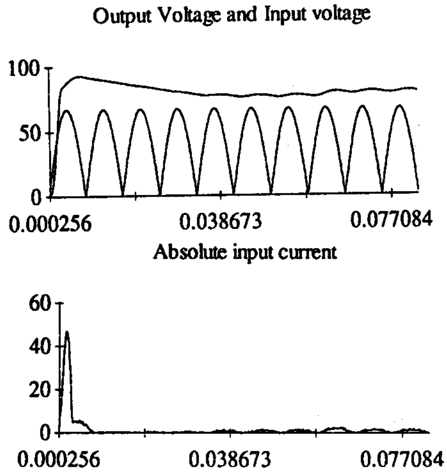


Fig. 5. Boost type ZCS series resonant AC to DC converter

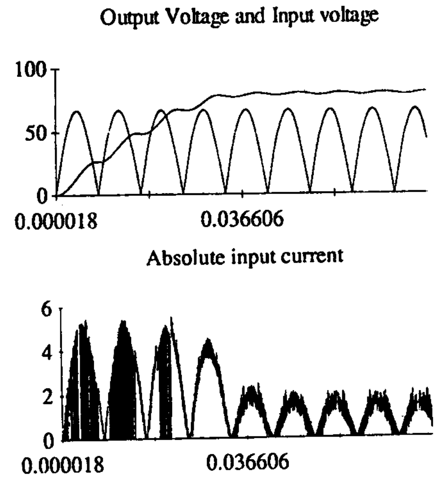


Fig. 6. Switched buck-Boost type ZCS series resonant AC to DC converter

References

[1] MANIAS, S., and ZIOGAS, P.D.: 'An SMR topology with suppressed DC link components and predictive line current wave shaping', IEEE Industry Application Society Annual Meeting, 1986, pp.630-639
[2] LIU, K.H., and L, Y.L.: 'Current waveform distortion in power factor correction circuits employing discontinous-mode boost converters', IEEE Power Elect. Spec.Conf., 1989, pp. 825-829
[3] KAZERANI, M., ZIOGAS, P.D., and JOOS, G.: 'A novel current waveshaping technique for solid-state input power factor conditioners', IEEE Trans. Ind. Elect., 1991, 38,(1), pp. 72-78
[4] SEBASTIAN, J., UCEDA, J., COBOS, J.A., and GIL, P.: 'Using zero-current-switched quasi-resonant converters as power factor preregulator', IEEE Industry Elect. Conf., 1991, pp.225-230
[5] KHERLUWALA, M.H., STEIGERWALD, R.L., and GURUMOORTHY, R.: 'Performance characterization of a high power factor power supply with a single power stage', IEEE Industry Application Society Annual Meeting,Ind., 1992, pp. 659-665
[6] KO, J.H., HONG, S.S., ANN, T.Y., and YOUN, M.J.: 'Dynamic modeling and current control technique for quantum series resonant converter with non-periodic integral cycle mode', International Journal of Electronics, 1991, pp. 885-897
[7] TRABERT, S.G., and ERICKSON, R.W.: 'Steady state anaysis of the duty cycle controlled series resonant converter', IEEE Power Electron. Spec. Conf. Rec., 1987, pp. 545-546