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A New Digital Current Control AC-DC Converter for Wind Turbine

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***Abstract*—In this paper, a new digital hysteresis current control for ac-dc converters is presented. The new control circuit has the peak and valley current detectors which are comprised of an RC integrator, comparator and R-S flip-flop. These current detectors can detect the peak and valley reactor currents in real time. The proposed control circuit structure and the operation principle are explained with the simulation result. As a result, it is confirmed that both peak and valley currents are detected instantaneously using the proposed method.**

Keywords—digital control; hysteresis current control; ac-dc converter; wind turbine

I. Introduction

The renewable energy power generation has been widely promoted to prevent global warming. Especially, the wind power generation is one of the renewable energy source in the world. It is known as an inexpensive renewable energy compared to the photovoltaic or biomass power generation [1], [2]. To promote further introduction of the wind power generation, a novel three phase synchronous generator has been proposed as shown in Fig. 1. This generator needs no slip rings and brushes. It also realizes maintenance free without rare-earth magnets. The rated output power of the generator is 2 kVA, the rated speed is 1800 rpm, the number of poles is 4 and the rated frequency is 60 Hz. [3], [4]. To transmit the generator to the dc-bus in the renewable energy system, an ac-dc converter is necessary at the latter part of a wind power generator.

Control methods of ac-dc converters are selected by the power amount from the continuous current mode control, the boundary one and the discontinuous one. The continuous current mode control is generally utilized to decrease the peak value of reactor current in the large power amount application [5], [6]. Furthermore, the continuous current mode control is classified into the average, peak and hysteresis current controls [7]-[9]. The hysteresis current control can obtain higher stability than the other control methods. However, it is difficult to detect the peak and valley currents instantaneously in the digital control circuit unless a fast sampling A-D converter and a fast processing circuit are used. To improve the stability of digital control ac-dc converters, real time current detection is important.

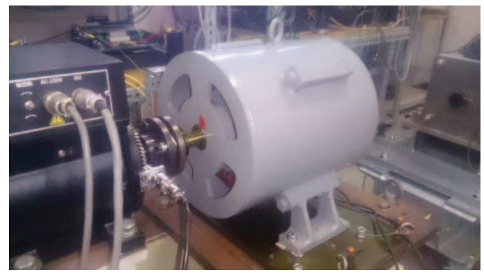

Fig. 1. Test machine of novel generator.

Thus, a new digital hysteresis current control which achieves the real time detection of peak and valley currents is presented in this paper. The peak current detector has been already studied for dc-dc converters [10]. It consists of an RC integrator, comparator and R-S flip-flop. The proposed hysteresis current control detects the valley current using almost the same circuit with the peak current detector. Therefore, real time response can be realized in both peak and valley currents detection. The proposed current control ac-dc converter is supposed to connect each phase of the novel synchronous generator. The rated power of ac-dc converter is 600 W. In Section II, the circuit structure and the operation principle of proposed method are described. In Section III, the operation waveforms of the simulation are shown when the output power is 600 W and 300 W.

II. Operaton Principle

The structure of ac-dc converter is shown in Fig. 2. e_{ac} is the alternating input voltage, i_{ac} is the alternating input current, L is the reactor, C_o is the output capacitor, e_i is the full rectified input voltage, i_L is the reactor current, e_L is the voltage of detected by the sensing resistor R_s, e_o is the output voltage and R_o is the load resistor. The control circuit detects e_i, e_o and e_L.

The proposed digital control circuit is illustrated in Fig. 3. The digital value of e_i and e_o are entered into PI controllers

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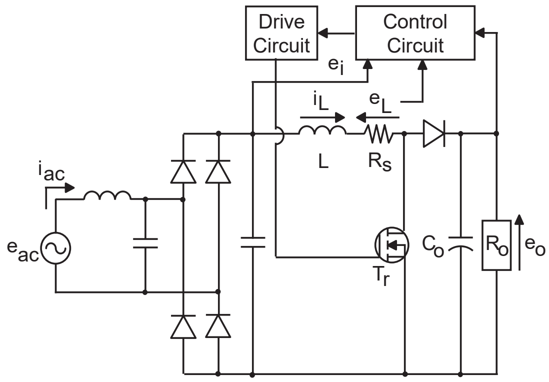


Fig. 2. Structure of ac-dc converter.

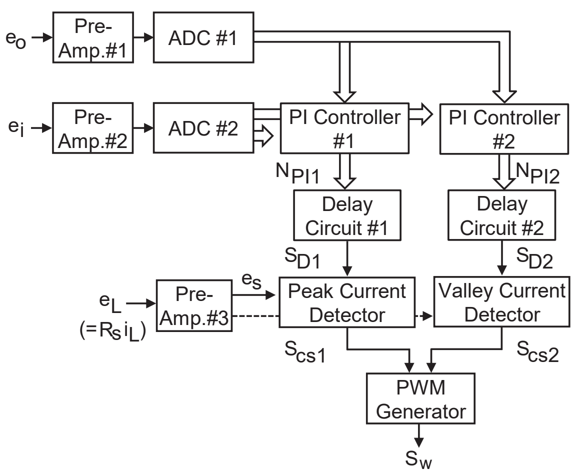
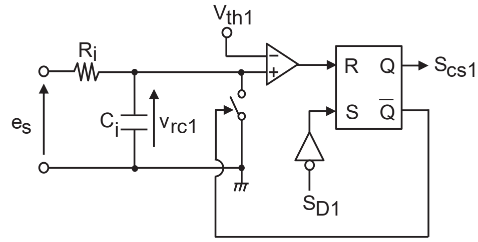
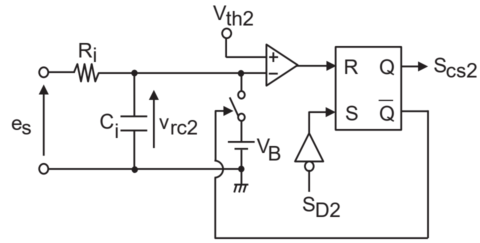


Fig. 3. Proposed digital control circuit.



(a) Peak current detector.



(b) Valley current detector.

Fig. 4. Reactor current detectors.

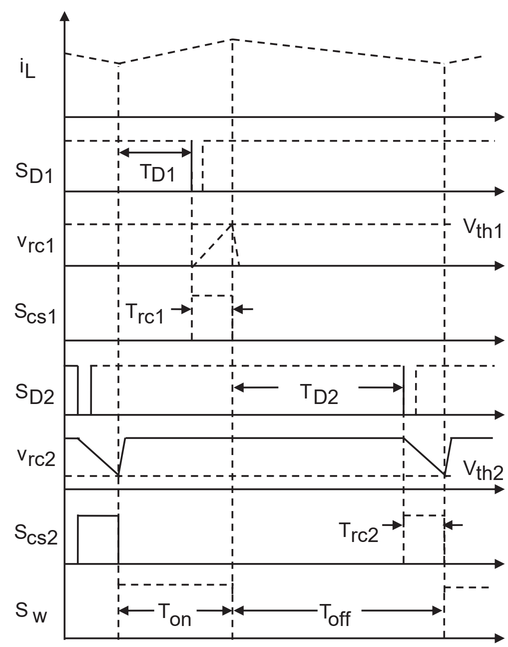


Fig. 5. Operation waveforms.

which calculate digital feedback values N_{PI1} and N_{PI2} to keep the regulation of e_o. Delay circuits #1 and #2 generate the delayed signals S_{D1} and S_{D2} based on N_{PI1} and N_{PI2}. S_{D1} and S_{D2} determine the detecting start point of i_L. The peak and the valley current detectors receive S_{D1} and S_{D2}, respectively. e_s is sent to the detectors for sensing the peak current and the valley current. S_{cs1} and S_{cs2} correspond to the peak current detection and the valley current detection. S_w is the signal of T_r to turn on and turn off.

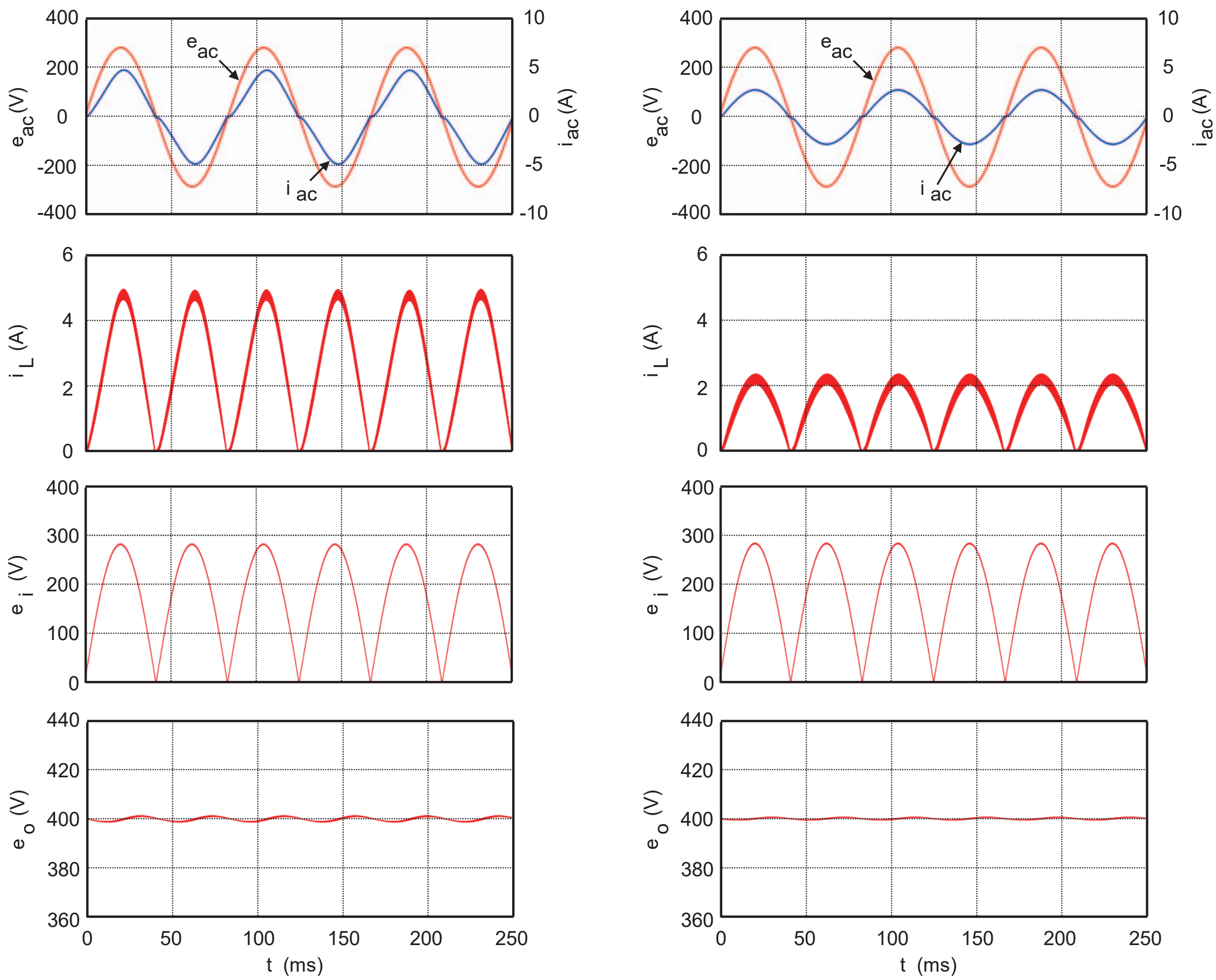
Figure 4 (a) and (b) show the peak current detector and the valley current detector, respectively. These detectors are composed of the RC integrator, comparator and R-S flip-flop. Once S_{D1} is turned off, the ramp voltage v_{rc1} becomes large in Fig. 4(a). Since the bias voltage V_B is connected in parallel to C_i, v_{rc2} is decreased after S_{D2} is turned off in Fig. 4(b). v_{rc1} and v_{rc2} are compared to the threshold voltage V_{th1} and V_{th2}, respectively. S_{cs1} and S_{cs2} are on-state during the reactor current sensing.

Figure 5 shows operation waveforms of the hysteresis current control. At first, T_{D1} is calculated based on N_{PI1}. It determines the detecting start point of i_L for the peak current detection. When S_{D1} is turned off, the current sensing is begun and S_{cs1} is turned on. When v_{rc1} reaches V_{th1}, S_{cs1} and S_w are turned off. This moment represents the peak current detection. In the valley current detection, N_{PI2} determines T_{D2}. The valley current sensing is begun when S_{D2} is turned off. As well as the peak current detection, the valley current is detected by using v_{rc2} and V_{th2}. After the valley current detection, S_{cs2} is turned off and S_W is turned on. In Fig. 5, T_{rc1} and T_{rc2} mean current sensing periods. Also, the on-time T_{on} and the off-time T_{off} are equal to T_{D1}+T_{rc1} and T_{D2}+T_{rc2}, respectively.

III. Observed Waveforms in Steady-State

In this section, observed waveforms of the proposed method are discussed by simulation results. e_{ac} is 200 Vrms, the input voltage frequency is 60 Hz, the desired value of e_o is 400 VDC, R_s is 0.05 Ω, L is 3 mH, C_o is 2000 μF and the rated power is 600 W. The parameters of control circuit are represented as below. A-D converters for e_o and e_i are 12 bit, R_i is 2.2 kΩ, C_i is 1200 pF, V_B is 5 V, V_{th1} is 0.5 V and V_{th2} is 4.5 V.

Figure 6 shows observed waveforms of the proposed method in the steady-state. The output power is 600 W in Fig. 6(a) and 300W in Fig. 6(b). It is found that the proposed method can be performed without any problem as an ac-dc converter operation. e_o is regulated accurately even when the output power is changed. The switching frequency is changed by value of i_L. In Fig. 6(a), the highest switching frequency is 87.8 kHz at the top of i_L and the lowest frequency is 43.2 kHz at the bottom. The power factor is 0.989 and the total harmonic distortion THD is 11.6 %. Besides, the power factor is 0.999 and the THD is 4.41 % in Fig. 6(b).



(a) Output power is 600 W.

(b) Output power is 300 W.

Fig. 6. Observed waveforms of proposed method in steady-state.

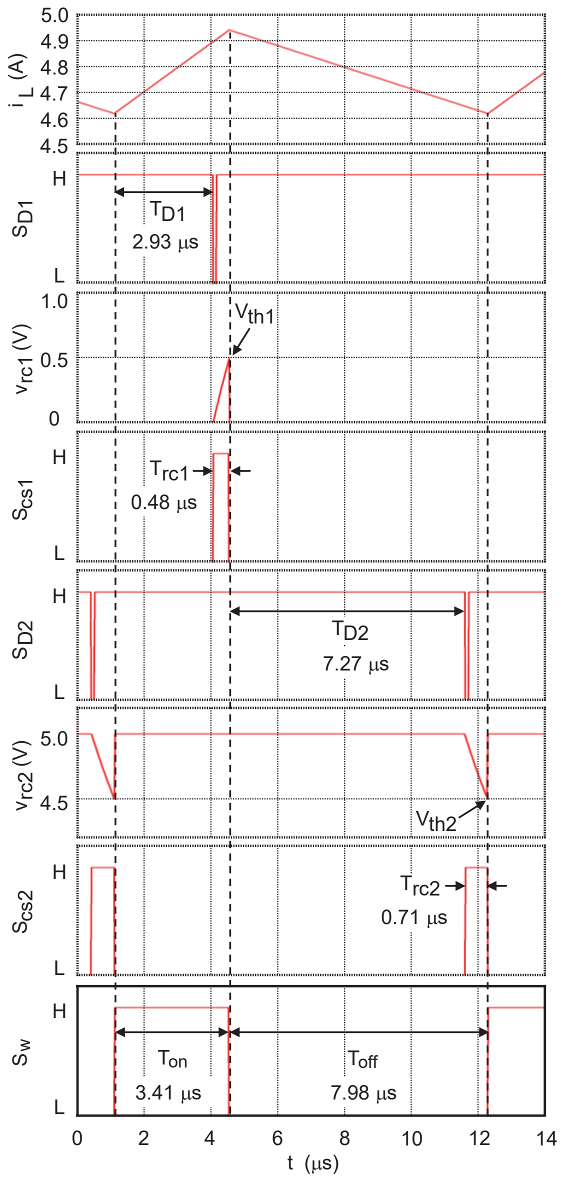


Fig. 7. Operation waveforms at the top of i_L when the output power is 600 W.

Figure 7 shows the peak and valley current detection at the top of i_L when the output power is 600 W. In the period of T_{on}, the detection of i_L is started when S_{D1} is turned off. v_{rc1} is increased after the current detection. S_{cs1} is turned off as soon as v_{rc1} reaches V_{th1}. At this moment, the S_w is turned off. As shown in Fig. 7, T_{D1} is 2.93 μs, T_{rc1} is 0.48 μs. T_{on} is 3.41 μs. Similarly, the valley current detection is started at the moment S_{D2} is turned off. T_{D2} is 7.27 μs, T_{rc2} is 0.71 μs and T_{off} is 7.98 μs. It is found that T_{rc1} and T_{rc2} is changed by the value of i_L and T_{D1} and T_{D2} are modified to regulate e_o. As a result, it is revealed that the digital hysteresis current control capable of real time current detection is realized.

IV. Conculusion

In this paper, the new digital hysteresis current control for ac-dc converter is presented. The peak and valley currents are detected in real time by the detectors composed of the RC integrator, comparator and R-S flip-flop. The proposed method is applied to 600 W ac-dc converter for the wind power generation and the basic operation is clarified. As a result, the proposed method realizes the new digital hysteresis current control without the delay of the peak and valley currents detection.

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