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전동차용 PWM 정류기를 위한 집전기(pantograph) 접점상태 검출방법 및 비접촉상태를 고려한 PWM 정류기 제어기법

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Pantograph Detachment Detector and Control Scheme for a PWM Rectifier Considering Pantograph Detachement Condition

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ABSTRACT

The pantograph contact can be disrupted due to irregularities in the motion. The pantograph detachment prohibits the current flow and makes the system uncontrollable. During the pantograph detachment period, the control error are accumulated by the integral property of the controller. The output of the controller, therefore, can be induced to be an extremely large value. When the pantograph is reattached, the extremely large output of the controllers causes a very high overshoot (or undershoot) of the line current and the DC-link voltage. This work proposes a new method for detecting the pantograph bouncing conditions and designs a controller considering such conditions based on the pantograph bouncing detector.

1. INTRODUCTION

A single-phase PWM rectifier has been used in traction applications. An example configuration is shown in Fig. 1(a). The source power is supplied through a pantograph and a transformer. There have been studies on the effects of the pantograph detachment on the power converter system, the detection methods, or the proper control scheme[1]~[4]. Recently, Mochizuka and Kusumi, Mori, and Kobayashi[1] presented a new method that can identify the contact loss of a pantograph by using an electrical circuit consisting of capacitors and resistance. However, since the electrical circuit is located in the high voltage (25kV) line side, the voltage rating of the capacitors are required to be large enough. Obviously, the high-voltage rating parts enlarge the circuit size, and increase the cost. Thus, the high-voltage detection cirucuit may not be desirable.

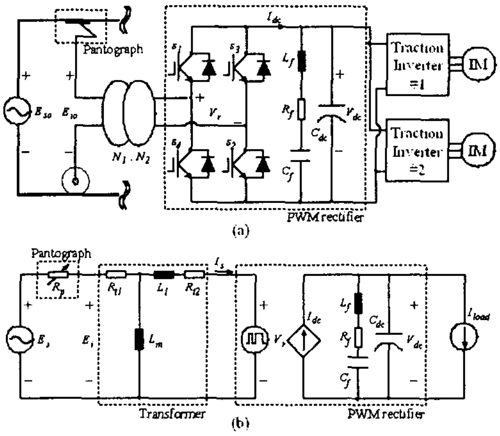

Fig. 1 Model of a PWM rectifier having a pantograph contact with the AC overhead line for taction applications : (a) the structure of a single-phase PWM rectifier, (b) the electrical model of the PWM rectifier, $E_s = (N_2/N_1)E_{so}$ where $E_i = (N_2/N_1)E_{io}$.

This work proposed a simple pantograph detachment detector and a control scheme for a PWM rectifier considering the pantograph detachment condition. The proposed detector consisting of only a simple microelectronic analog circuit, is capable of identifing the pantograph detachment condition without using a high voltage monitoring system nor a complex hardware/software.

2. EFFECTS OF THE PANTOGRAPH DETACHMENT ON THE PWM RECTIFIER OPERATION

The mechanical contact between the pantograph and the overhead power line can be dis-

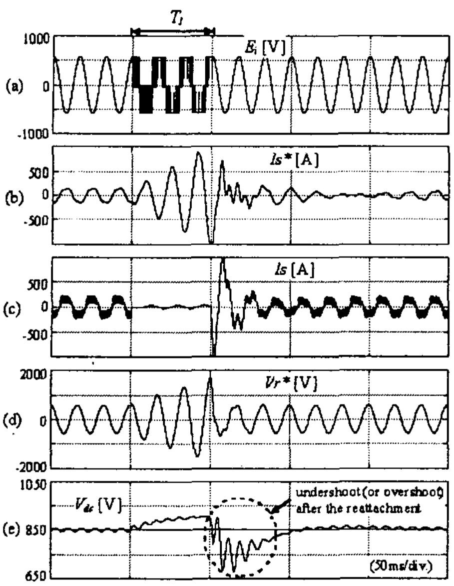

Fig. 2. Simulation result of the PWM rectifier operation with a conventional control scheme under the pantograph detachment condition, where the DC-load was about 13%.

rupted due to irregularities in the motion or in the track geometry. When the gap distance becomes too large and/or the gap voltage becomes too small, the pantograph and the overhead line are disconnected both electrically and mechanically. In this case, the electrical disconnection prevents the current flowing and the energy trasmission. Since the energy does not transmit through the AC side, the real power flow or the DC-link voltage level does not depend on the PWM switches' status, and the system becomes uncontrollable. Under such an uncontrollable condition, the integral action of the DC-link voltage controller and the current controller may increase extremely the output and the internal states of the controllers. When the pantograph is reattached, the extremely increased output of the controllers may cause improper behavior. Fig. 2 shows a simulation result of E_i, I_s^*, I_s, V_r^* and V_{dc}, when the pantograph detachment occurs during 3cycles (50 ms) and the DC-link load current is about -13% (60A). During the pantograph detachment period, the amplitude of I_s^* was increased to 1000A, due to the decrease of V_{dc}. When the pantograph is reattached, the extremely large current command and the current controller output caused a large undershoot in the DC-link voltage. The overshoot or undershoot of the DC-link votlage depends mainly on the duration of the pantograph detachment period and the control gain.

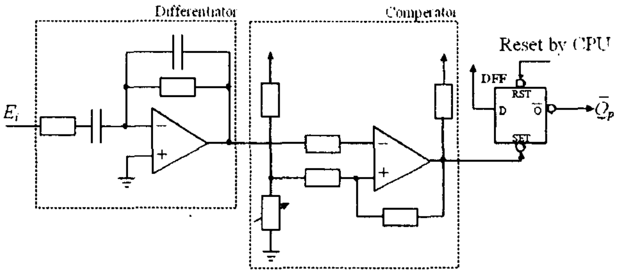

Fig. 3 Example circuit of the proposed pantograph detachment detector.

3. PRINCIPLE OF THE PROPOSED PANTOGRAPH DETACHMENT DETECTOR

When the pantograph and the overhead line are disconnected both electrically and mechanically, the pantograph detachment can be modelled by using a very large value resistance $R_p \cong \infty$. Fig. 1(b) shows the model of the pantograph and the PWM rectifier where $I_{dc}(t) = (s_1 - s_3)I_s(t)$, the switching function $s_j \in \{0,1\}$, $j = 1 \cdots 4$, $s_4 = 1 - s_1$, $s_2 = 1 - s_3$ and I_{load} is the DC-load current. Note that $R_p \cong 0$ under a normal condition or the arc discharge condition, while $R_p \cong \infty$ under the pantograph detachment condition. By the superposition theorem, E_i can be expressed by the source voltage term E_s and the PWM rectifier input voltage term V_r such that

$$E_i = Z_1(s)E_s + Z_2(s)V_r \tag{1}$$

where

$$Z_1(s) = \frac{R_{t1} + sL_m \parallel (R_{t2} + sL_l)}{R_{t1} + R_p + sL_m \parallel (R_{t2} + sL_l)},$$

$$Z_2(s) = \frac{R_p s L_m V_r}{(R_p + R_{t1} + sL_m)(R_{t2} + sL_l + sL_m) - s^2 L_m^2}$$

When the pantograph detachment occurs, *i.e.*, $R_p \cong \infty$, the source voltage measurement can be expressed by only V_r under the assumption that $wL_m \gg R_{t2} + wL_l$ such that

$$\lim_{R_p \to \infty} E_i = \frac{sL_m V_r}{R_{t2} + sL_l + sL_m} \simeq V_r. \tag{2}$$

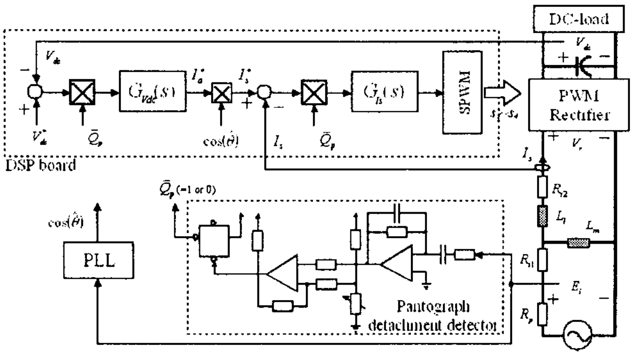

Fig. 4 Structure of the proposed control scheme for a PWM rectifier.

Obviously, V_r is a PWM voltage, and thus the value of E_i is V_{dc} or $-V_{dc}$. That is, E_i is not a sinusoidal signal anymore but a high frequency PWM signal. This fact is used for constructing the pantograph detachment detector. The proposed method distinguishes the pantograph detachment condition from a normal condition by monitoring the derivative of E_i. Fig. 3 shows an example schematic of the proposed pantograph detachment detection circuit that consists of a differentiator, a comparator and a flip-flop. The comparator is to compare the amount of the derivative with a given criteria level, and judge whether the present situation is a normal condition or a pantograph detachment condition. One can avoid the misjudgement caused by the high frequency noise in a normal condition by setting the critical level to high. The flip-flop output $\overline{Q_p} = 0$ under the pantograph detachment condition, while $\overline{Q_p} = 1$ under a normal condition. A control processor can identify the condition of the pantograph by reading $\overline{Q_p}$ from the flip-flop at any time.

4. CONTROL SCHEME USING THE PANTOGRAPH DETACHMENT DETECTOR

When the pantograph is detached, the energy cannot transfer to the AC-side, regardless of the condition of the PWM switches. Therefore, the DC-link voltage cannot be controlled by any control scheme under the pantograph detachment condition. The main objective of the proposed control scheme is to prevent the controllers from performing erroneously, when the pantograph is reattached. Fig. 4 shows the structure of the proposed control scheme for a single-phase PWM rectifier, where G_{Vdc} is the DC-link voltage controller and G_{I_s} is the current controller. The pantograph detachment detector output $\overline{Q_p}$ is multiplied to the control error terms and the PWM voltage command so that the control errors are fed into the controllers under a normal condition, while zero values are fed into the controllers under the pantograph detachment condition. This is equivalent to suspend the controllers' action during the pantograph detachment period. The internal states of the controller are maintained. The pantograph detachment detector is reset by the control processor at every sampling period.

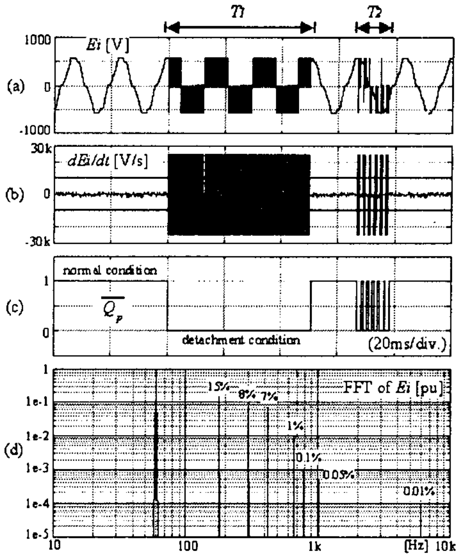

Fig. 5 Simulation result of the pantograph detachment and bouncing detection : (a) E_i, (b) dE_i/dt, (c) $\overline{Q_p}$, and (d) the frequency spectrum of E_i.

5. SIMULATION RESULTS

To verify the feasibility of the proposed pantograph detachment detector and the proposed control scheme, computer simulation studies were performed by Matlab simulink with the parameters given by Table 1. To test the robustness of the pantograph detachment detector against noises or harmonics, the source voltage includes 15%-3rd(180Hz), 8%-5th(300Hz), 7%-7th(420Hz),

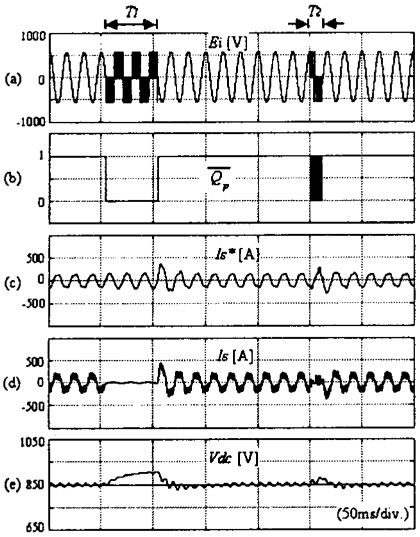

Fig. 6 Simulation result of the PWM rectifier operation with the proposed control scheme under the pantograph detachment condition, where the DC-load was about 13%.

Table 1 Simulation parameters

R_{t1}[ohm]	12m	R_{t2}[Ohm]	1.8m
L_m[mH]	100	L_l[mH]	1.8
V_{dc}^*[V]	850	$N_1 : N_2$	22000:417

1%-11th(660Hz), 0.1%-13th(780Hz), 0.05%-17th (1020Hz), and 0.01%-6kHz harmonics as shown in Fig. 5(a). Fig. 5 shows the simulation result of the pantograph detachment detector when the pantograph is detached during T1 (3 cycles, 50ms), and 500Hz pantograph bounces are placed during T2. Plots (a)-(d) show E_i, dE_i/dt, and $\overline{Q_p}$, respectively. Plot (d) shows the frequency spectrum of E_i showing the existence of the harmonic terms in the source voltage. One can see from Fig. 5 that the detector can provide the exact information about the pantograph condition under not only a normal condition but also a highly distorted source voltage condition.

Fig. 6 shows the simulation result of the proposed control scheme using the pantograph detachment detector under the condition that a -13% (60A) DC-load is applied, the pantograph is detached during T1, and 500Hz pantograph bouncing is placed during T2. Plots (a)-(e) show E_i, $\overline{Q_p}$, I_s^*, I_s, and $\{V_{dc}^*, V_{dc}\}$, respectively. One can see from Fig. 6 that the controller inputs are blocked during T1 and T2 such that the output of the DC-link voltage controller is kept to be constant. Therefore, when the pantograph is reattached, the undershoot of V_{dc} gets to be negligible. Note also that small overshoots of I_s^* and I_s in Fig. 6(c) and (d) are due to not the erroneous behavior of the controller, but the DC-link voltage error, since the DC-link voltage error increases during T1 and T2. As shown in Fig. 6, the proposed controller works without any erroneous behavior under the pantograph bouncing condition T2 as well as the pantograph detachment condition T1.

6. CONCLUDING REMARKS

This work proposed a new pantograph detachment detector and a control scheme for a PWM rectifier considering the pantograph detachment condition. The pantograph detachment detector is a simple analog filter consisting of a differentiator, a comparator, and a flip-flop. It enables us to monitor the condition of the pantograph at any time without using a high voltage monitoring system nor a complex hardware/software. The proposed detector is distinguished from the existing detection methods by its simplicity and low cost. The proposed control scheme is to prevent the controllers from doing an erroneous behavior such as causing a large overshoot in the current and the DC-link voltage when the pantograph is reattached. We have demonstrated the superior performance through computer simulations.

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